

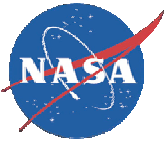
Strawman Roadmap

*Presentation to the Exploration Transportation
Systems Strategic Roadmap Committee*

Steve Cook

February, 2005

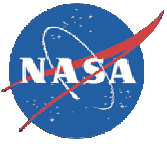




Briefing Purpose



Present a strawman space transportation roadmap, philosophy and methodology for committee consideration



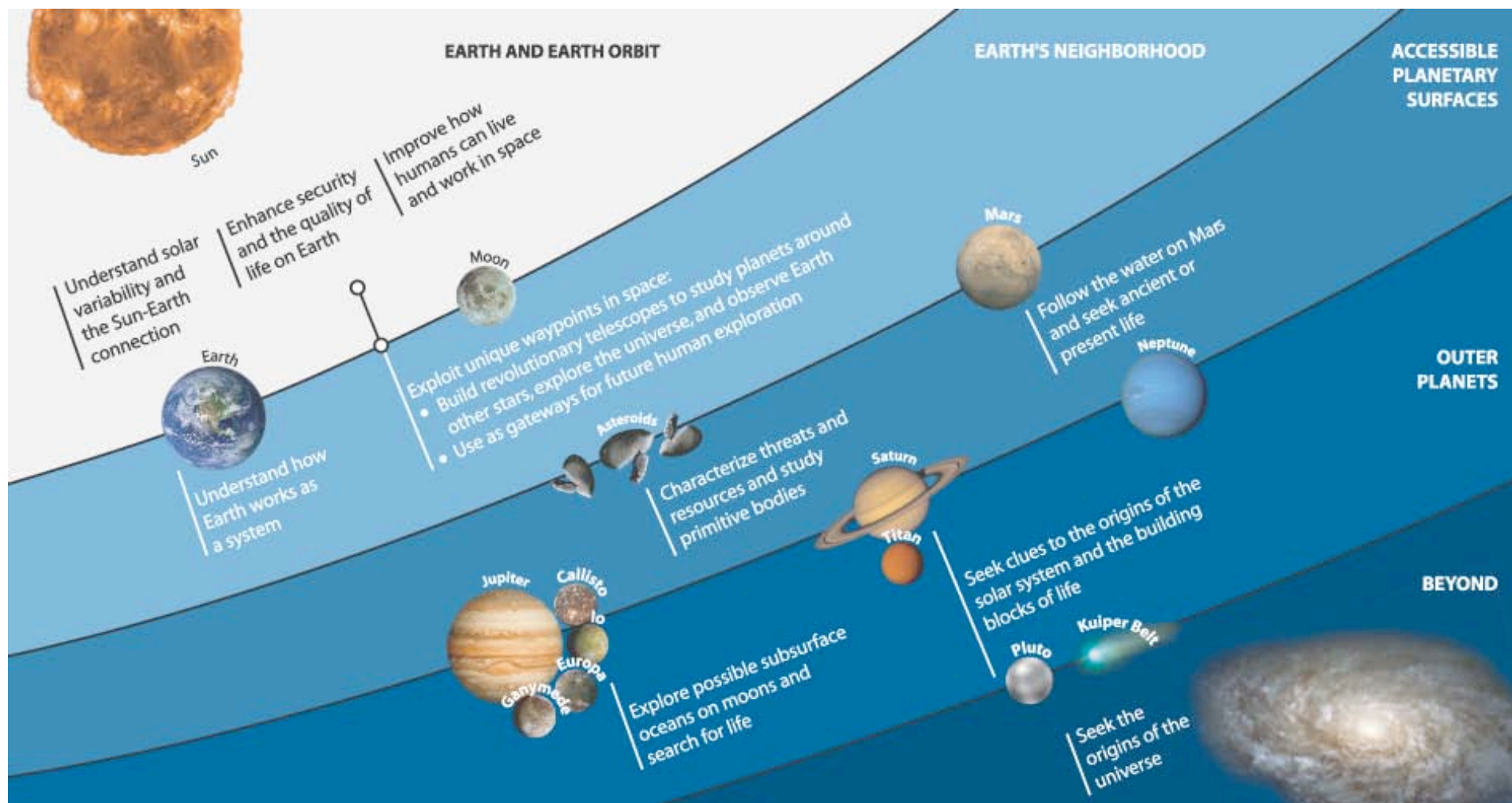
Agenda

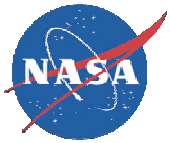


- ▶ **◆ Scope of Exploration Transportation**
- ◆ Space Transportation Needs by Spiral**
 - Approach
 - Capability vs. Mission Need
 - Potential Themes
- ◆ Strawman Space Transportation Roadmaps**

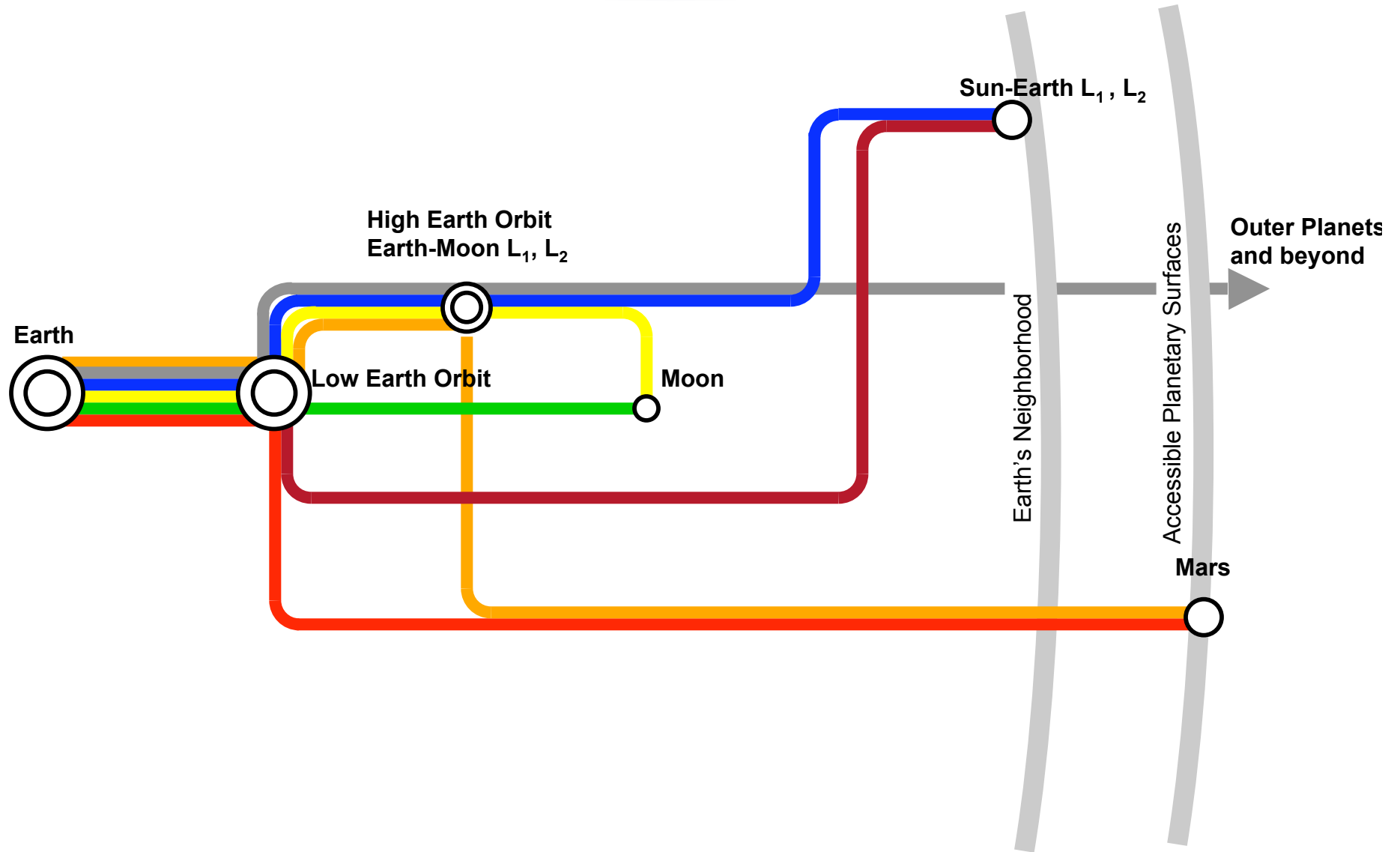


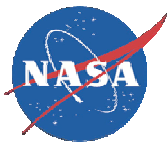
Potential Range of Space Transportation Missions



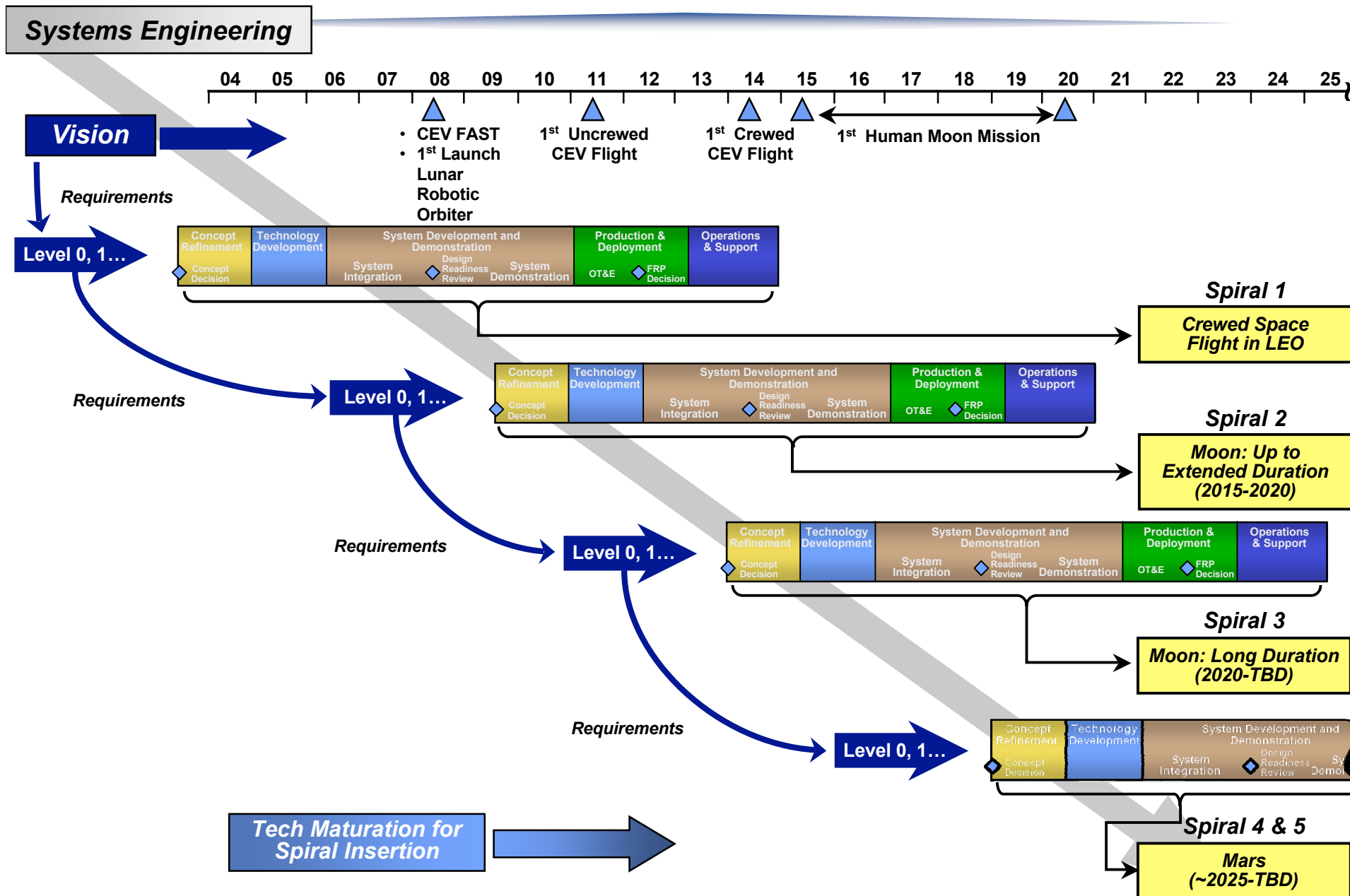


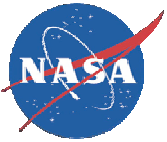
Exploration Transportation Routes





Acquisition Timeline





Agenda



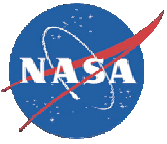
- ◆ **Scope of Exploration Transportation**
- ◆ **Space Transportation Needs by Spiral**
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- ◆ **Strawman Space Transportation Roadmaps**



Approach



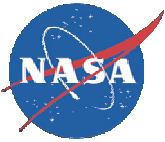
- ◆ **Developed a transportation function vs. capabilities matrix for each Spiral.**
- ◆ **Within each matrix, transportation capabilities were assessed to be probable, possible, or not applicable for included mission phases.**
- ◆ **Themes and capabilities phasing across and within all Spirals were then derived from the matrices.**



Transportation Function Definitions



- ◆ ***Earth to Orbit*** – Pre-launch through ascent to low Earth orbit
- ◆ ***Earth Orbital*** – Earth orbit phase of all Spirals and missions (including reentry from orbit)
- ◆ ***Earth to Moon*** – Transfer from Earth orbit to Lunar surface and surface operations (includes intermediate points such as L1, Lunar orbit, etc.)
- ◆ ***Moon to Earth Return*** – Ascent from Lunar surface to recovery at Earth's surface (includes return from intermediate points such as L1, Lunar orbit, etc.)



Transportation Function Definitions (cont'd)



- ◆ ***Earth to Mars*** – Transfer from Earth orbit to Mars surface and surface operations (includes intermediate points)
- ◆ ***Mars to Earth Return*** – Ascent from Mars surface to recovery at Earth's surface (includes return from intermediate points)
- ◆ ***Solar System*** – Includes all non-Lunar and non-Mars science and exploration missions

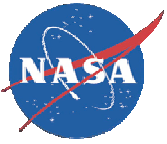


Agenda



- ◆ **Scope of Exploration Transportation**
- ◆ **Space Transportation Needs by Spiral**
 - Approach
 - Capability vs. Mission Need
 - Potential Themes
- ◆ **Strawman Space Transportation Roadmaps**





Key Transportation Capabilities

- ◆ ***Transportation Elements*** – Architecture level building blocks (systems) that require supporting systems / technologies / capabilities
- ◆ ***Propulsion Systems*** – Supporting propulsion technologies and capabilities
- ◆ ***Vehicle Systems*** – Supporting vehicle technologies and capabilities (non-propulsion)
- ◆ ***Human Systems*** – Systems, technologies and capabilities that support human space flight
- ◆ ***Operations*** – Pre-launch, launch and mission operations technologies and capabilities



Space Transportation Needs Assessment

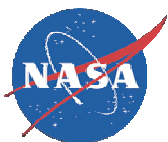
Spiral 1

Example



Key Transportation Capabilities	Key Transportation Functions																		
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
Transportation Elements																			
ELV / EELV	X	O																	
EELV Derived	O	O																	
Shuttle Derived	O	O																	
Crew Exploration Vehicle		X			X														
Launch Escape System		X																	
Upper Stage / Transfer Stage				X	X		X			X			X			X			X
In-Space Propellant / Supply Depot																			
Planetary Capture / Entry							X						X						X
Planetary Landing							X						X						X
Surface Mobility							O			O			X			O			
Planetary Ascent										X						X			X
Reentry at Earth				X	X					X						X			X
Propulsion Systems																			
Chemical																			
Liquid																			
Cryogenics	X	X		O	O		O			O			O			O			O
Storables	X			X	X		O			O			O			O			O
Solid / Hybrid	X	O					O			O			O			O			O
Launch Assist	O	O																	
Nuclear Thermal																			
Electric																			
Low Power (<50kw)				O			O			O			O			O			X
Medium Power (50-500kw)							O			O			O			O			
High Power (>500kw)																			
Propellantless																			
Aeroassist (Capture / Entry)				O	X					O			O			O			O
Sails																			O
Tethers																			
Vehicle Systems																			
Lightweight Structures	O	O		O			O			X			X			X			X
Deployable Systems				O			O			X			X			X			X
Radiation Hardening / Shielding					O		O			O			O			O			O
MMOD Protection					O														
Efficient Thermal Systems							O			O			O			O			O
Avionics/Intelligent System Health Management	X	X		X	X		X			X			X			X			X
Power (generation, conversion, distribution)	X	X		X	X		X			X			X			X			X
Communications and Data Handling	X	X		X	X		X			X			X			X			X
Guidance, Navigation & Control	X	X		X	X		X			X			X			X			X
Reaction Control/Orbital Maneuvering	X	X		X	X		X			X			X			X			X
Cryo Fluid Management				O	O		O			O			O			O			
Systems Engineering and Integration (inc. M&S)	X	X		X	X		X			X			X			X			X
Human Systems																			
Life Support		X			X														
Radiation Protection																			
Biomedical Countermeasures																			
Crew Systems: In-space		X			X														
Crew Systems: Surface																			
Artificial Gravity																			
Operations																			
Automated																			
Rendezvous and Docking				X	O		O			O			O			O			O
Maneuvering				X	O		X			X			X			X			X
Decision Making				O			O			O			O			O			X
On-Orbit Assembly and/or Repair (EVA)					O														
Launch and Payload Processing / Range	X	X																	
Recovery				O	X					X						X			X
ISRU Propellants/Fluids																			
Propellant Transfer																			
Communications and Navigation Network	X	X		X	X		X			X			X			X			X

X - Probable Need O - Potential Need Difference Not Applicable



Space Transportation Needs

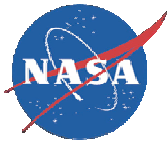
Difference Between Spiral 1 and 2

Example



Key Transportation Capabilities	Key Transportation Functions																		
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
Transportation Elements																			
ELV / EELV	X	O	O																
EELV Derived	O	O	O																
Shuttle Derived	O	O	O																
Crew Exploration Vehicle		X			X			X			X								
Launch Escape System		X																	
Upper Stage / Transfer Stage				X	X			X	O		X		X			X			X
In-Space Propellant / Supply Depot													X						
Planetary Capture / Entry								X	O				X						X
Planetary Landing								X	O				X						X
Surface Mobility								O					X			X			
Planetary Ascent											X					X			X
Reentry at Earth				X	X					X						X			X
Propulsion Systems																			
Chemical																			
Liquid																			
Cryogenics	X	X	X	O	O	O		X	O		X		O			O			O
Storables	X			X	X	X		O	O		X		O			O			O
Solid / Hybrid	X	O	O										O			O			O
Launch Assist	O	O	O																
Nuclear Thermal																			
Electric																			
Low Power (<50kw)				O		O							O			O			X
Medium Power (50-500kw)													O			O			X
High Power (>500kw)																			
Propellantless																			
Aeroassist (Capture / Entry)				O	X					X			O			O			X
Sails																			X
Tethers																			
Vehicle Systems																			
Lightweight Structures	O	O	O	O		O		O	O		O		O			X			X
Deployable Systems				O		O		X	O		X		O			X			X
Radiation Hardening / Shielding					O			X	O		X		O			O			O
MMOD Protection					O			X	O										
Efficient Thermal Systems								X	O		X		O			O			O
Avionics/Intelligent System Health Management	X	X	X	X	X	X		X	O		X					X			X
Power (generation, conversion, distribution)	X	X	X	X	X	X		X	O		X		X			X			X
Communications and Data Handling	X	X	X	X	X	X		X	O		X		X			X			X
Guidance, Navigation & Control	X	X	X	X	X	X		X	O		X		X			X			X
Reaction Control/Orbital Maneuvering	X	X	X	X	X	X		X	O		X		X			X			X
Cryo Fluid Management				O	O	X		X	O		X		O			O			
Systems Engineering and Integration (inc. M&S)	X	X	X	X	X	X		X	X		X		X			X			X
Human Systems																			
Life Support		X			X			X			X								
Radiation Protection								X			X								
Biomedical Countermeasures																			
Crew Systems; In-space		X			X			X			X								
Crew Systems; Surface								X											
Artificial Gravity																			
Operations																			
Automated																			
Rendezvous and Docking				X	X	X		O	O		X		O			O			O
Maneuvering				X	X	X		X	O		X		X			X			X
Decision Making				O		O		O	O		O		O			O			X
On-Orbit Assembly and/or Repair (EVA)					O	O		O	O		O								
Launch and Payload Processing / Range	X	X	X																
Recovery				O	X						X					X			X
ISRU Propellants/Fluids																			
Propellant Transfer						O		O	O										
Communications and Navigation Network	X	X	X	X	X	X		X	O		X		X			X			X
X - Probable Need O - Potential Need Difference Not Applicable																			

X - Probable Need O - Potential Need Difference Not Applicable



Space Transportation Needs

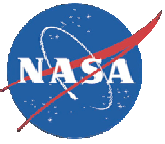
Spiral 2

Example



Key Transportation Capabilities	Key Transportation Functions																	
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return		
	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo
Transportation Elements																		
ELV / EELV	X	O	O															
EELV Derived	O	O	O															
Shuttle Derived	O	O	O															
Crew Exploration Vehicle		X			X		X			X								
Launch Escape System		X																
Upper Stage / Transfer Stage				X	X		X	O		X			X			X		X
In-Space Propellant / Supply Depot																		
Planetary Capture / Entry							X	O					X					X
Planetary Landing								O					X					X
Surface Mobility													X					
Planetary Ascent										X						X		X
Reentry at Earth				X	X					X						X		X
Propulsion Systems																		
Chemical																		
Liquid																		
Cryogenics	X	X	X	O	O	O	X	O		X			O			O		O
Storables	X			X	X	X	O	O		X			O			O		O
Solid / Hybrid	X	O	O										O			O		O
Launch Assist	O	O	O															
Nuclear Thermal																		
Electric																		
Low Power (<50kw)				O		O							O			O		X
Medium Power (50-500kw)													O			O		X
High Power (>500kw)																		
Propellantless																		
Aeroassist (Capture / Entry)				O	X					X			O			O		X
Sails																		X
Tethers																		
Vehicle Systems																		
Lightweight Structures	O	O	O	O		O	O	O		O			O			X		X
Deployable Systems				O		O				X			O			X		X
Radiation Hardening / Shielding					O					X			O			O		O
MMOD Protection					O					X								
Efficient Thermal Systems										X			O			O		O
Avionics/Intelligent System Health Management	X	X	X	X	X	X	X	O		X			X			X		X
Power (generation, conversion, distribution)	X	X	X	X	X	X	X	O		X			X			X		X
Communications and Data Handling	X	X	X	X	X	X	X	O		X			X			X		X
Guidance, Navigation & Control	X	X	X	X	X	X	X	O		X			X			X		X
Reaction Control/Orbital Maneuvering	X	X	X	X	X	X	X	O		X			X			O		X
Cryo Fluid Management				O	O	X				O			O			O		
Systems Engineering and Integration (inc. M&S)	X	X	X	X	X	X	X	X		X			X			X		X
Human Systems																		
Life Support		X			X			X			X							
Radiation Protection								X			X							
Biomedical Countermeasures																		
Crew Systems: In-space		X			X			X			X							
Crew Systems: Surface								X										
Artificial Gravity																		
Operations																		
Automated																		
Rendezvous and Docking				X	X	X		O			X		O			O		O
Maneuvering				X	X	X		X	O		X		X			X		X
Decision Making				O		O		O	O		O		O			O		X
On-Orbit Assembly and/or Repair (EVA)					O	O		O	O		O							
Launch and Payload Processing / Range	X	X	X															
Recovery				O	X											X		X
ISRU Propellants/Fluids																		
Propellant Transfer						O				O	O							
Communications and Navigation Network	X	X	X	X	X	X		X	O		X		X			X		X

X - Probable Need O - Potential Need Difference Not Applicable



Agenda



- ◆ **Scope of Exploration Transportation**
- ◆ **Space Transportation Needs by Spiral**
 - Approach
 - Capability vs. Mission Need
 - Potential Themes
- ◆ **Strawman Space Transportation Roadmaps**





Key Transportation Capabilities	Key Transportation Functions																		
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
Transportation Elements	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
ELV / EELV	X	O																	
EELV Derived	O	O																	
Shuttle Derived	O	O																	
Crew Exploration Vehicle		X			X														
Launch Escape System		X																	
Upper Stage / Transfer Stage				X	X		X			X			X			X			X
In-Space Propellant / Supply Depot																			
Planetary Capture / Entry																			
Planetary Landing																			

Themes:

Earth to Orbit

Transfer To/From & Orbital Operations

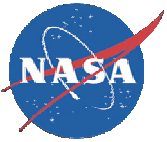
Descent / Surface Operations / Ascent

Earth Capture / Entry

Crew Support

Vehicle Systems

Operations



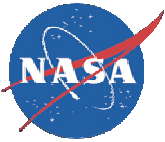
General Observations

- ◆ **Earlier Spirals exercise, to varying extent, most technologies needed for Mars exploration missions**
 - Many must be enhanced to meet later Spiral requirements (i.e., cryo fluid mgmt, radiation shielding, etc.)
- ◆ **Each Spiral also requires some new capabilities that were not required in earlier Spirals**
- ◆ **Economy may be realized by building later Spiral requirements into new elements for that Spiral.**



Theme: Earth to Orbit

- ◆ **Current ELV's**
 - Are likely to be able to satisfy all robotic and some cargo missions across all Spirals
 - May satisfy Spiral 1 with modifications for human rating
- ◆ **Shuttle hardware/systems may possibly be utilized in multiple applications**
- ◆ **Commercial capability may be able to satisfy some lift requirements (e.g., propellant)**
- ◆ **Spiral 1 may require a new upper stage for CEV launch**
 - May initially use current engine designs
 - May also have applicability (e.g., cargo, in-space transfer) in later Spirals
- ◆ **Spirals 2 and 3 may require enhanced launch capability, unless a significant orbital assembly capability is developed**
- ◆ **Spiral 4 will likely require significantly greater Initial Mass to Low Earth Orbit (IMLEO) than Spiral 1, 2 or 3**
 - This could be satisfied by heavier lift vehicles, propellant depots, more efficient launch/on-orbit assembly capability, etc.



Theme: *Transfer to and Orbital Operations*

Crew Exploration Vehicle



◆ Options bounded as:

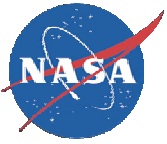
- *Basic CEV* capability provides crew habitat for launch, minimal delta-V capability for orbit maneuvering and de-orbit, and reentry
- *Full CEV* capability provides basic CEV capabilities, plus habitat function for in-space transfer and return, and trans-Earth injection delta-V

◆ Likely to be an evolution in CEV requirements across Spirals (TPS, propulsion capacity, lifetime, etc.)

◆ Automated rendezvous and docking is required across all Spirals

◆ CEV propulsion may require cryo-fluid management capabilities

◆ Lunar CEV may be capable of satisfying human ETO and return requirements for Spiral 4/5



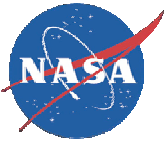
Theme: Transfer *To/From* and Orbital Operations

Transfer Stages



- ◆ **Spirals 2 and 3 will likely require new capabilities:**
 - A new in-space engine may be required
 - May require progressively larger stages (and corresponding larger lift capability) or multiple stages
 - May utilize non-nuclear advanced propulsion options

- ◆ **Spiral 4/5 may require significantly larger / multiple stages earlier Spirals**
 - Likely even if an orbital assembly capability or advanced propulsion is developed.

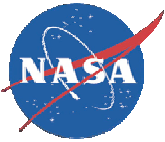


Theme: Transfer *To/From* and Orbital Operations

Nuclear Thermal Propulsion



- ◆ Lunar cargo mission in Spiral 3 may be used to demonstrate Nuclear Thermal Propulsion (NTP) system capabilities.
- ◆ Spiral 3 technologies provide basis for Spiral 4/5 high-power NTP propulsion options.
- ◆ NTP potentially reduces IMLEO requirements and / or improves trip time compared to all-chemical propulsion mission options.
- ◆ NTP ground test facilities must be addressed.

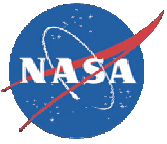


Theme: Transfer *To/From* and Orbital Operations

Electric Propulsion



- ◆ **Low to medium power Electric Propulsion (EP) systems support robotic solar system exploration across all Spirals**
- ◆ **Reusable low- to medium-power Solar EP systems reduce propellant requirements for Spiral 3 in-space tugs and lunar cargo**
 - Evolve from current kW-class EP system technologies.
- ◆ **High power Nuclear Electric Propulsion (NEP) systems reduce IMLEO for Spiral 4/5 cargo (Mega Watt-class) and piloted (Multi-Mega Watt-class) missions**
- ◆ **Possible options for high-power NEP have been identified:**
 - Achieve high power by clustering low- to medium-power electrostatic thrusters (increases propulsion system mass and complexity)
 - Develop high-power, high-thrust density electromagnetic thrusters (currently at low TRL)
- ◆ **Facility requirements for high-power / long-life EP ground tests must be addressed**

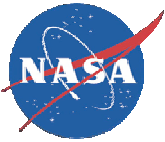


Theme: Transfer *To/From* and Orbital Operations

Other Advanced Technology Options



- ◆ **Advanced In-Space Propulsion Technology (APT) includes aeroassist, solar sails, & tethers**
- ◆ **Flight Demonstration is likely a prerequisite for infusion of these technologies**
- ◆ **APT enables cargo and robotic missions with higher payload mass fraction than conventional chemical systems for all Spirals**
- ◆ **APT has the potential to provide improved performance within a Spiral as the products of a technology maturation program are delivered**
- ◆ **APT flight demonstration may be achieved in conjunction with the robotic exploration**

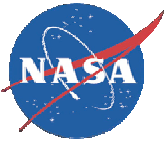


Theme: Descent / Surface Operations / Ascent

Entry and Landing



- ◆ **Propulsion requirements will likely be driven by architecture decisions**
- ◆ **Landers for Spirals 2 and 3 may be common, particularly when cargo is pre-deployed for Spiral 3**
- ◆ **Spiral 3 and subsequent Spirals may have unique precision landing requirements**
 - Based upon need to rendezvous with pre-deployed surface assets (ballistic landing for Spiral 3 and aeroassist for Spiral 4/5)
- ◆ **Spiral 4/5 may require significantly larger landers (and corresponding greater initial mass in orbit) than Spirals 2 and 3**
- ◆ **Spiral 4/5 may have unique requirements based upon selection of the propulsion option, including potential for in-situ resources utilization**

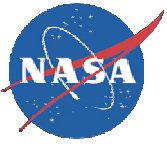


Theme: Descent / Surface Operations / Ascent

Ascent Propulsion



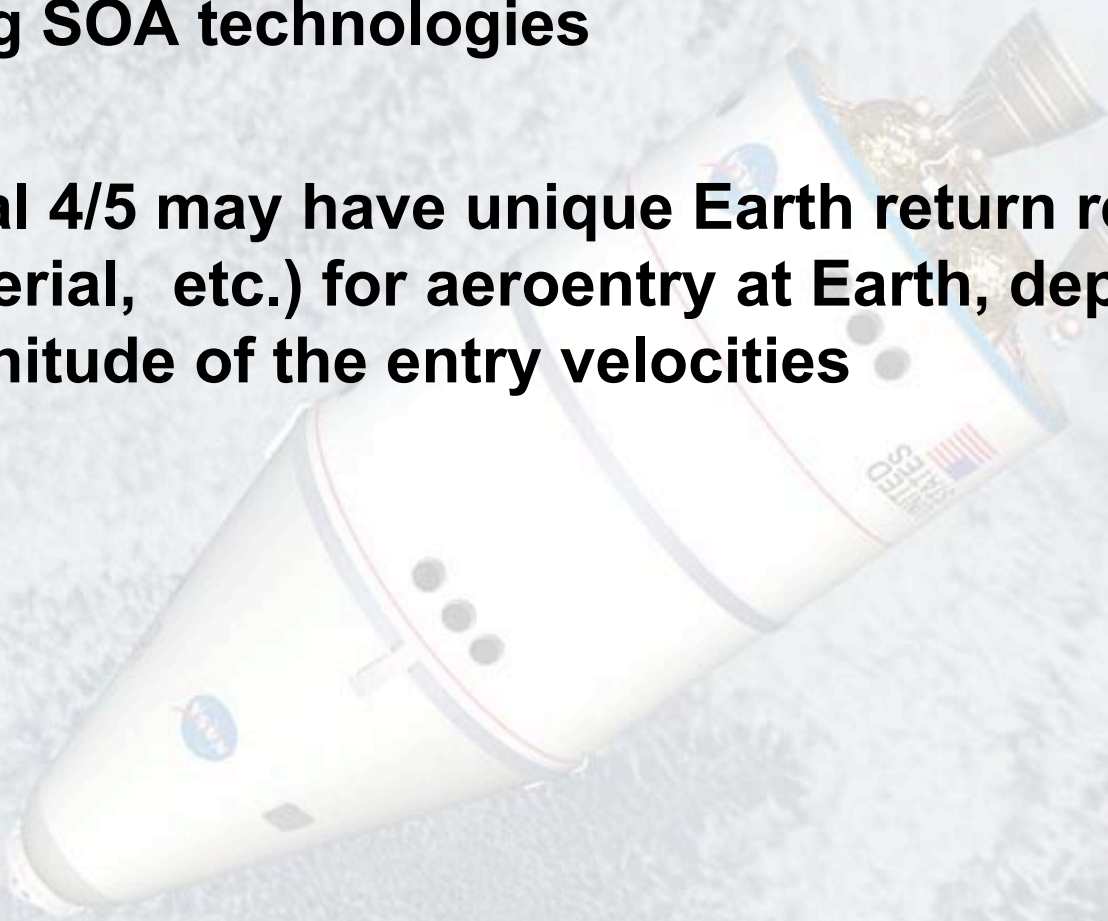
- ◆ **State-of-the-Art lander technology may be applicable for some robotic and cargo missions across all Spirals**
- ◆ **Spiral 1 has only robotic ascent requirements, which can be addressed using SOA propulsion**
- ◆ **Overall transportation architecture (e.g., common habitat/split habitat) may drive ascent requirements**
- ◆ **Ascent technologies may be impacted by choice of propellant and the potential use of in-situ resources**
- ◆ **Spiral 4/5 may require significantly larger ascent (and corresponding greater initial mass in orbit) than Spirals 2 and 3, even if advanced chemical propulsion is developed**



Theme: Earth Capture / Reentry



- ◆ **Spirals 1 through 3 may likely have little or no Earth return requirements beyond those already addressed using SOA technologies**
- ◆ **Spiral 4/5 may have unique Earth return requirements (material, etc.) for aeroentry at Earth, depending on the magnitude of the entry velocities**





Cross Cutting Theme: Crew Support



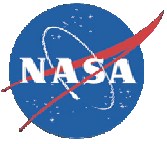
- ◆ **Technology advancement may not be required for Spiral 1.**
- ◆ **Advancements in radiation protection may be required for Spiral 2 and beyond**
- ◆ **Longer duration missions (late Spiral 2, Spiral 3) may benefit from closed loop Environmental Control & Life Support Systems (ECLSS); required for Spiral 4/5**
- ◆ **Understanding the transportation system implications of artificial gravity or biomedical countermeasures is needed prior to implementation on Spiral 4/5**
- ◆ **Artificial gravity, if required, is a significant driver to transportation system design**
- ◆ **Robust, highly reliable ECLSS, including in-flight repair capability is critical**



Cross Cutting Theme: Vehicle Systems



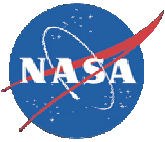
- ◆ Vehicles systems include lightweight structures, deployable systems, radiation and MicroMeteoroid and Orbital Debris (MMOD) protection, GN&C, TPS, etc
- ◆ Depending on CEV architecture, SOA vehicle system technologies may be appropriate for Spiral 1
- ◆ System technology improvements may be necessary to meet the requirements of later Spirals



Cross Cutting Theme: Operations



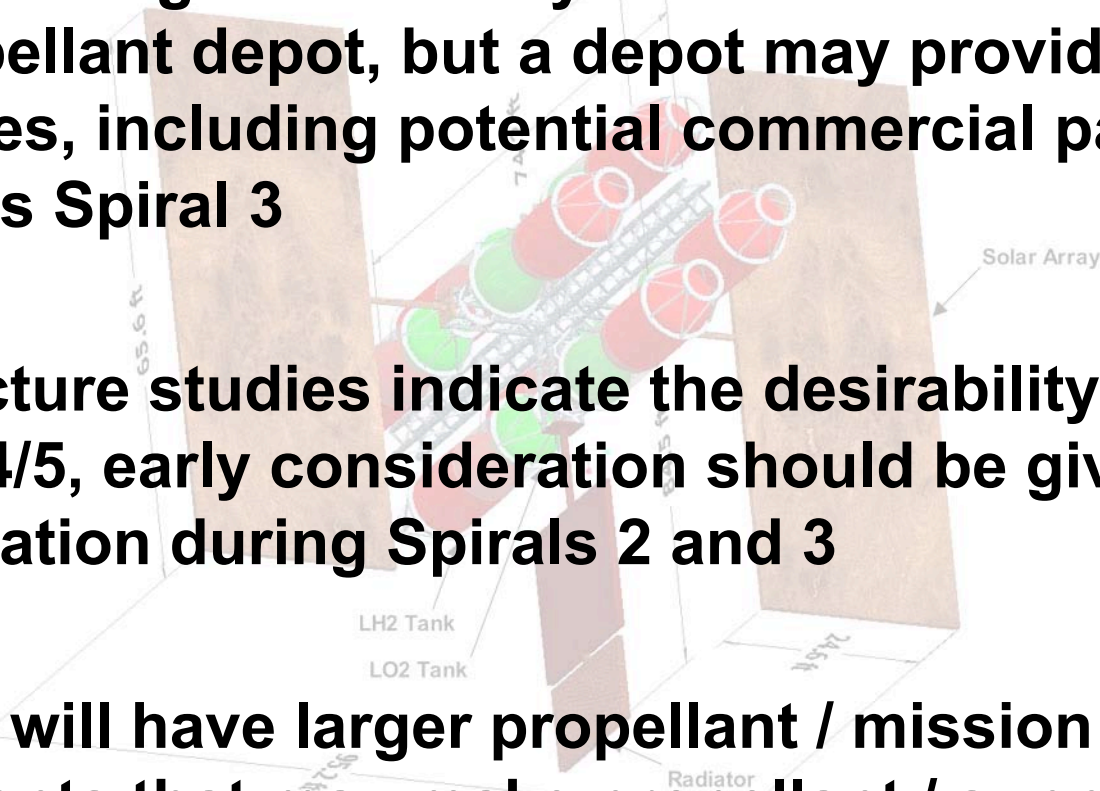
- ◆ **Limitations in launch vehicle lift capability will likely drive in-space assembly requirements**
- ◆ **Spiral 4/5 trip times and communication lags for human flight may require a high degree of mission autonomy**
- ◆ **Operational complexity will increase with mission duration**
- ◆ **The amount of in-space infrastructure (depots, assembly, communications, etc.) will increase for later Spirals**

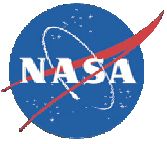


Cross Cutting Theme: Operations (cont'd)



- ◆ Spirals 1 through 3 will likely have no basic requirement for a propellant depot, but a depot may provide some advantages, including potential commercial participation, as early as Spiral 3
- ◆ If architecture studies indicate the desirability of depots in Spiral 4/5, early consideration should be given to demonstration during Spirals 2 and 3
- ◆ Spiral 4/5 will have larger propellant / mission requirements that may make propellant / supply depot architectures viable





Agenda

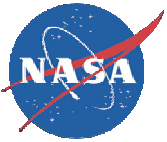


◆ Scope of Exploration Transportation

◆ Space Transportation Needs by Spiral

- Approach
- Capability vs. Mission Need
- Potential Themes

▶ ◆ Strawman Space Transportation Roadmaps

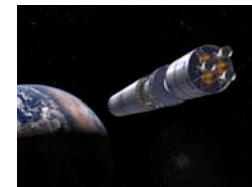
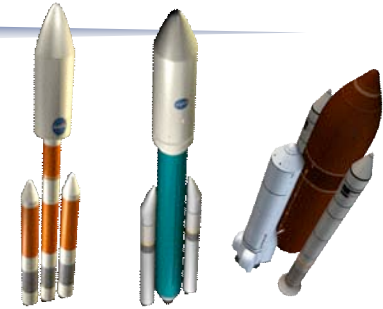


Roadmaps

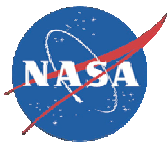
*Based on Themes**



- ◆ **Earth to Orbit**
- ◆ ***Transfer To* and Orbital Operations**
- ◆ **Descent / Surface Operations / Ascent**
- ◆ **Destination Orbital Operations and *Transfer From***
- ◆ **Earth Capture / Reentry**



** Integrated the Crew Support, Vehicle Systems and Operations Themes due to their cross-cutting nature*



Earth to Orbit Roadmap

- ▲ - Program Milestone
- ◆ - Downselect Decision
- ▲ - IOC Milestone
- - Concept / Focused Technology
- - Development / Production
- - Operations / Support

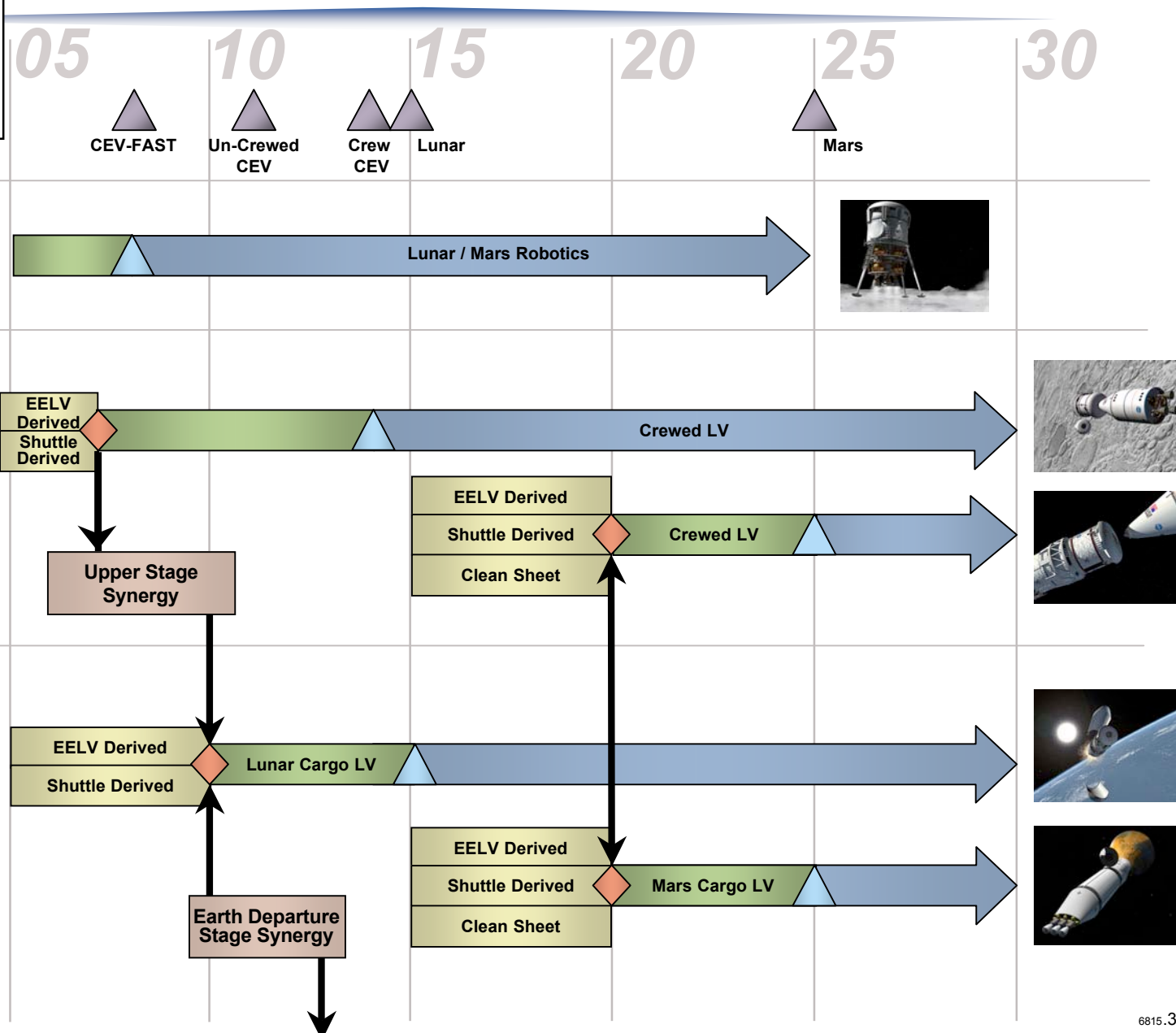
Robotic

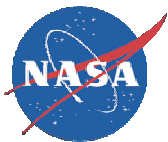
Crew

- Do we use different vehicles for cargo vs. crew? Mixed fleet?
- Do we use Shuttle or EELV-derived? Clean Sheet?
- Role for commercial?

Cargo

- Degree and timing of heavy-lift needs?
- Do we use Shuttle or EELV-derived? Clean Sheet?
- Do we want to build/modify a vehicle that can also meet Mars heavy lift needs?
- Role for commercial?





Transfer To and Orbital Operations Roadmap



- ▲ - Program Milestone
- ◆ - Downselect Decision
- ▲ - IOC Milestone
- - Concept / Focused Technology
- - Development / Production
- - Operations / Support

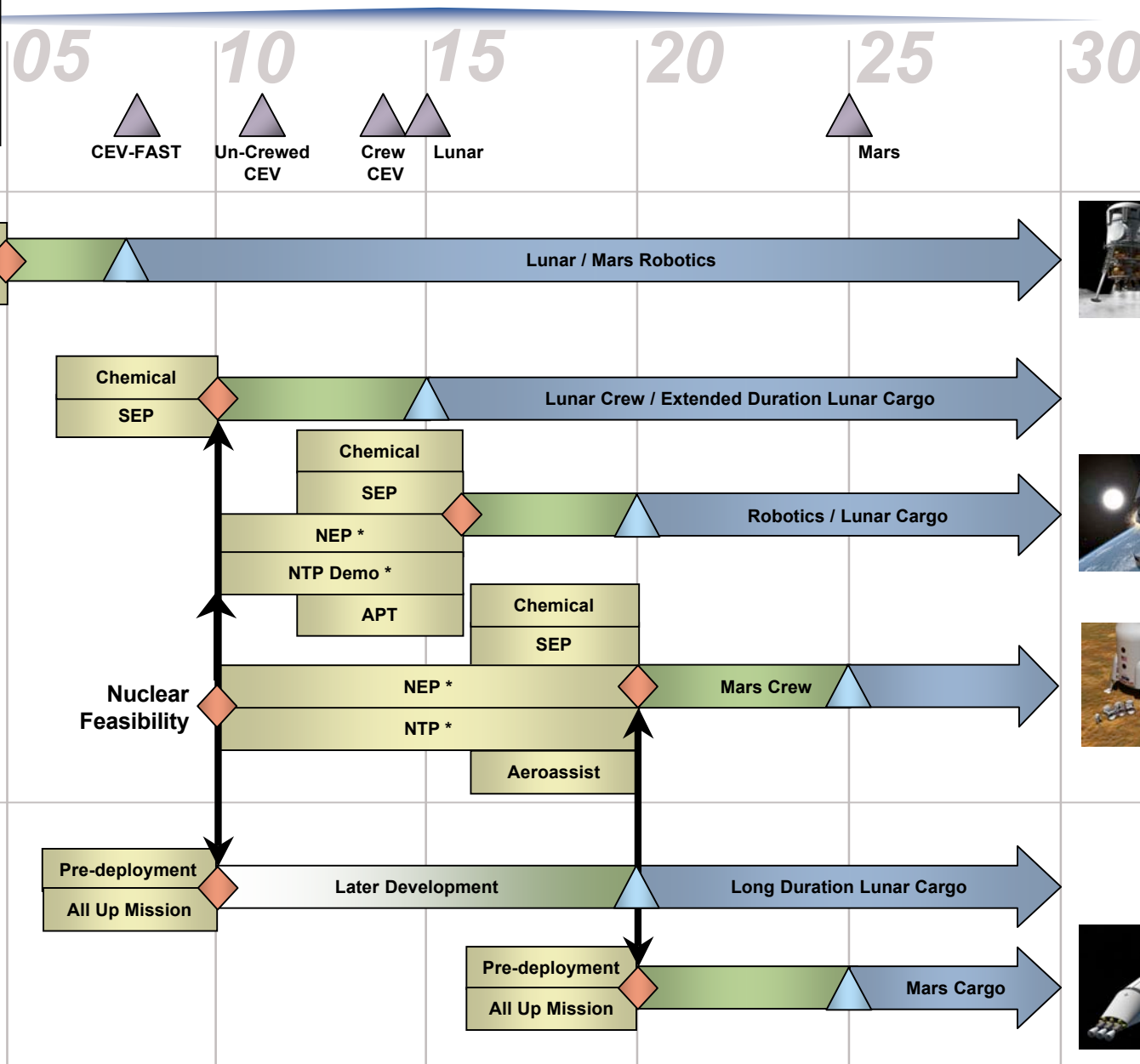
In-space Propulsion

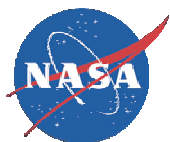
- Are the transfer stage and upper stage common?
- Is spiral departure from LEO required?
- What propulsion is used for capture maneuvers?
- LEO propellant depot required?
- When is nuclear needed?

Cargo Delivery

- Is the cargo delivered separately or with the crew?

Note: * will require a research and technology effort prior to this focused phase





Transfer To and Orbital Operations Roadmap (cont'd)



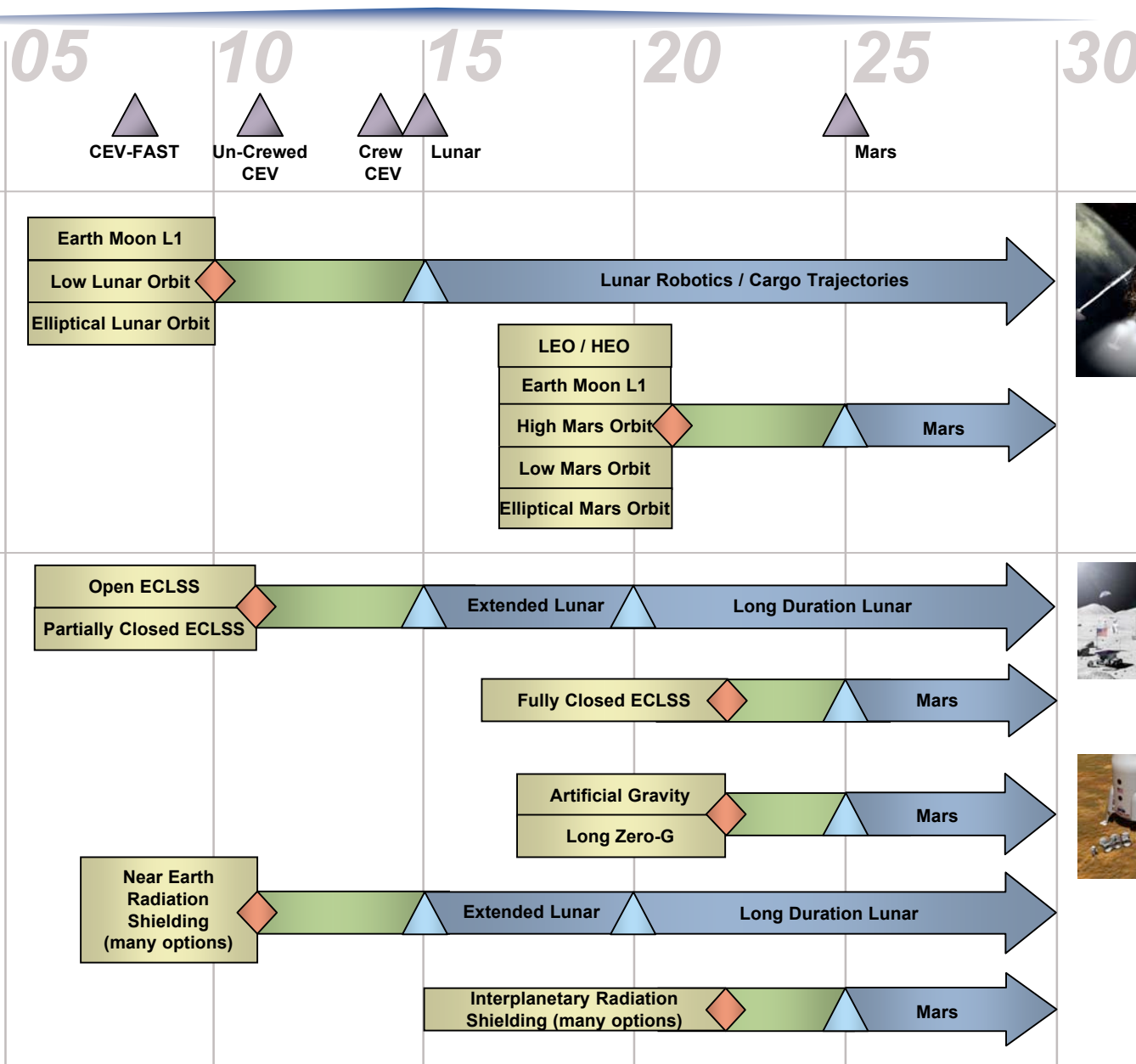
- ▲ - Program Milestone
- ◆ - Downselect Decision
- ▲ - IOC Milestone
- - Concept / Focused Technology
- - Development / Production
- - Operations / Support

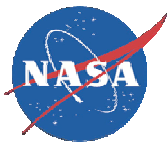
Trajectory

- Where are the staging points?
- What is the nature of the parking orbit? (low, elliptical)
- Is gravity assist used for Mars?

Crew Support

- When is a closed ECLSS required?
- Is artificial gravity required?
- Is crew radiation exposure an issue?





Descent / Surface Operations / Ascent Roadmap



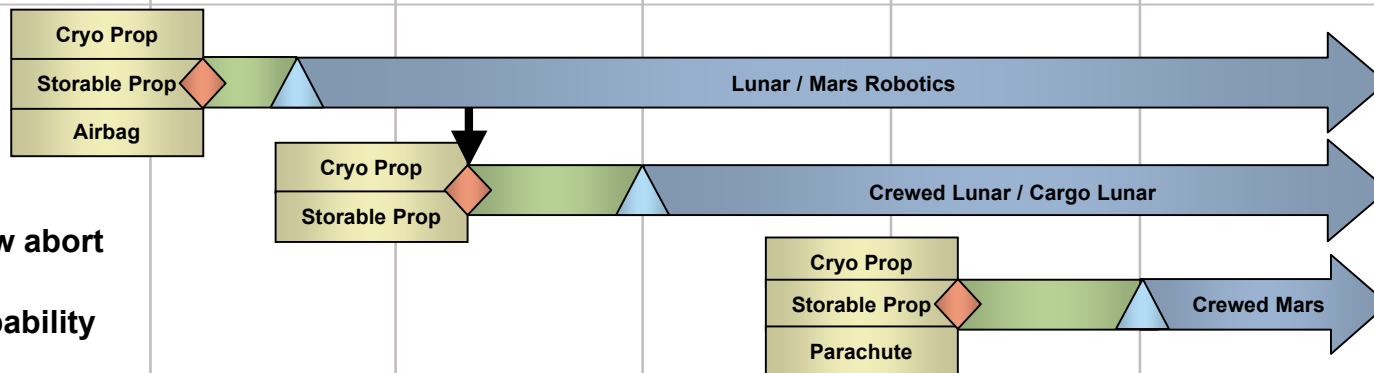
- ▲ - Program Milestone
- ◆ - Downselect Decision
- ▲ - IOC Milestone
- - Concept / Focused Technology
- - Development / Production
- - Operations / Support

05 10 15 20 25 30

CEV-FAST Un-Crewed CEV Crew CEV Lunar Mars

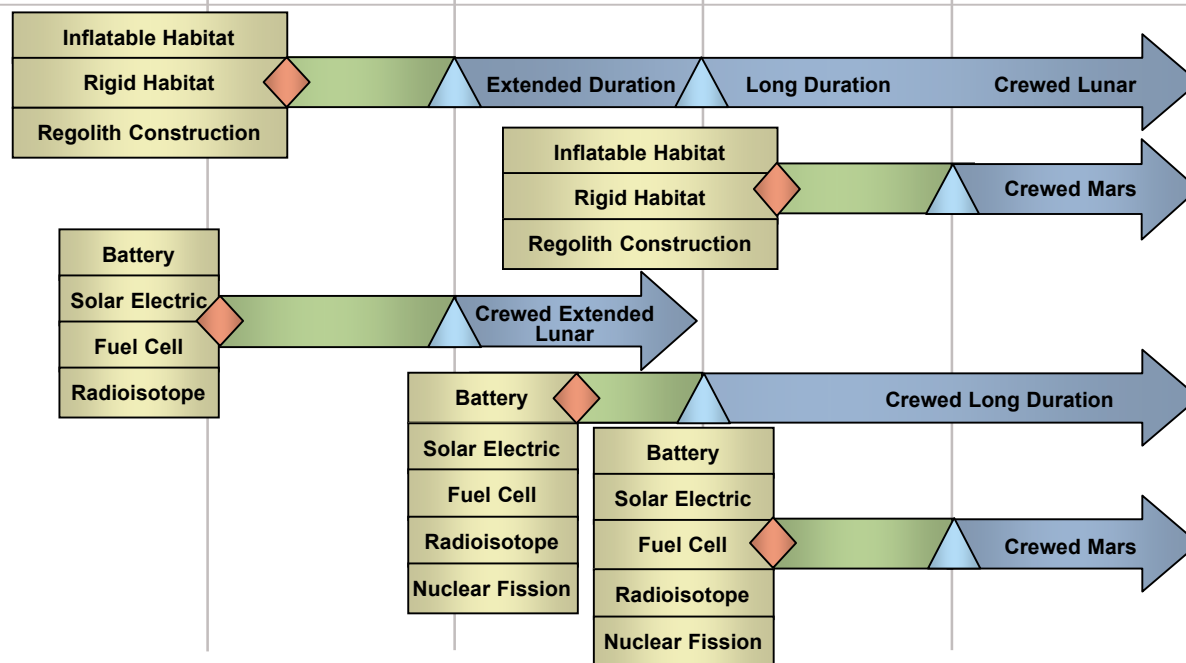
Descent

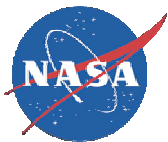
- Is the descent stage reusable?
- Would the entire crew descend to the surface?
- What are the crew abort options?
- Is engine out capability required?



Habitat

- Is the habitat reusable?
- How long is the surface stay time?
- How long is the surface storm period?
- What is the power source?
- Are the resources predeployed before the crew?





Descent / Surface Operations / Ascent Roadmap (cont'd)



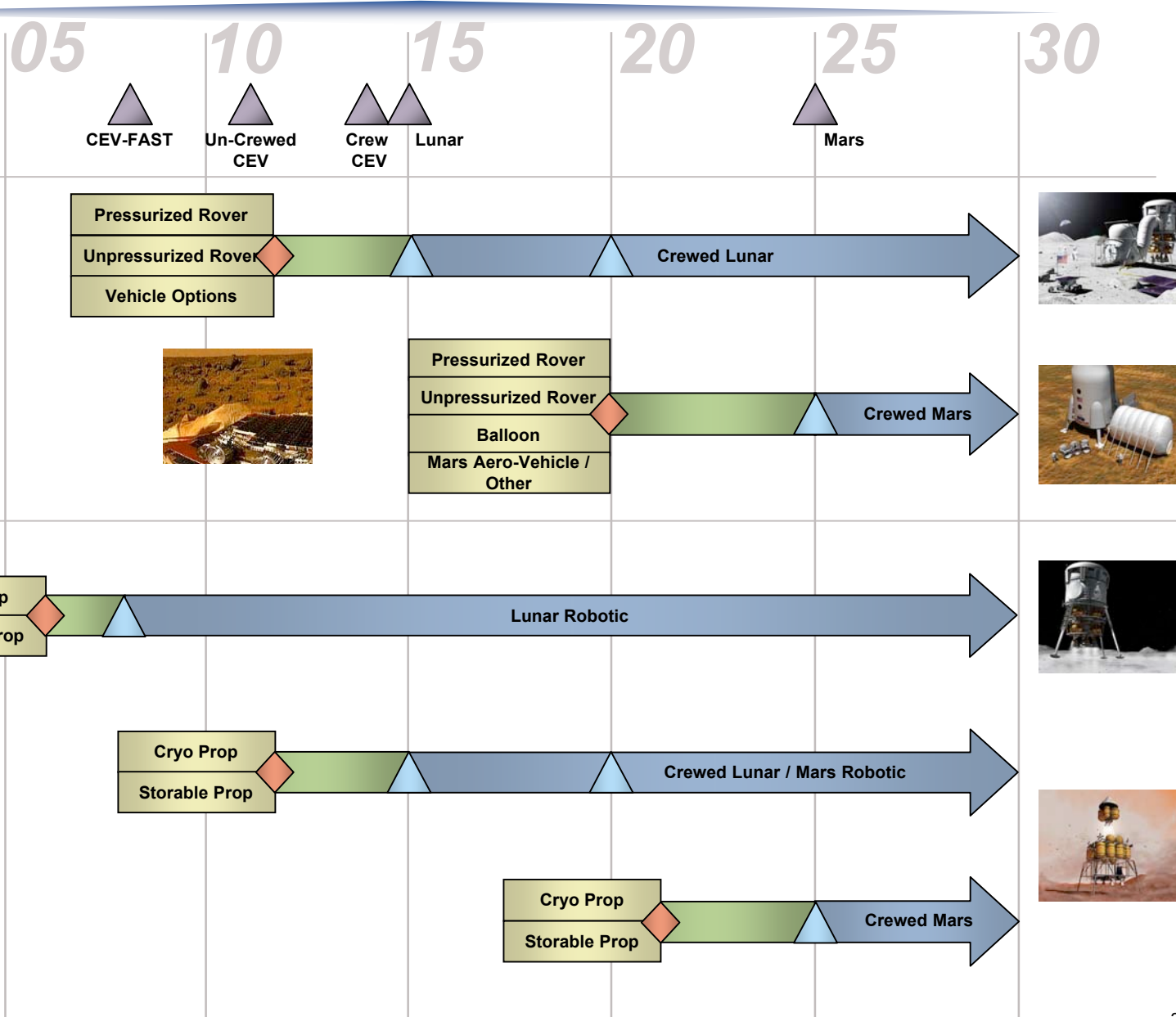
- ▲ - Program Milestone
- ◆ - Downselect Decision
- ▲ - IOC Milestone
- - Concept / Focused Technology
- - Development / Production
- - Operations / Support

Surface Mobility

- What mobility systems would be considered?

Ascent

- Is the ascent stage reusable?
- In-Situ propellant and other consumables?
- Ascent orbit impact on descent systems?
- What is the degree of return mass required?





Destination Orbital Operations and *Transfer From* Roadmap



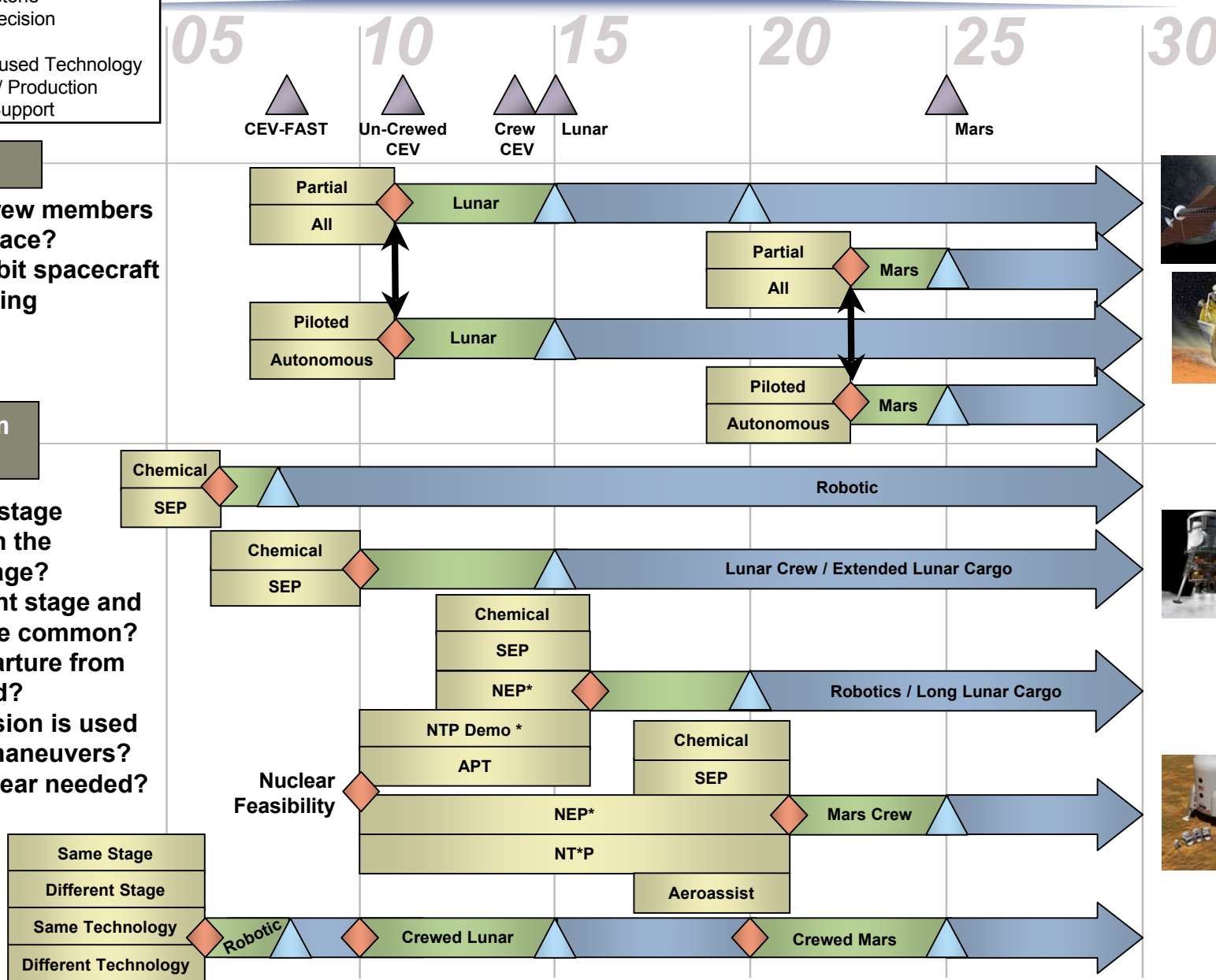
- ▲ - Program Milestone
- ◆ - Downselect Decision
- ▲ - IOC Milestone
- - Concept / Focused Technology
- - Development / Production
- - Operations / Support

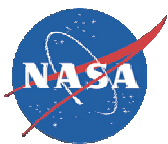
Orbit Ops

- How many crew members from the surface?
- How is on orbit spacecraft station- keeping performed?

Transfer From Propulsion

- Is the return stage common with the outbound stage?
- Are the ascent stage and transfer stage common?
- Is spiral departure from orbit required?
- What propulsion is used for capture maneuvers?
- When is nuclear needed?





Destination Orbital Operations and *Transfer From* Roadmap (cont'd)



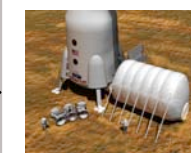
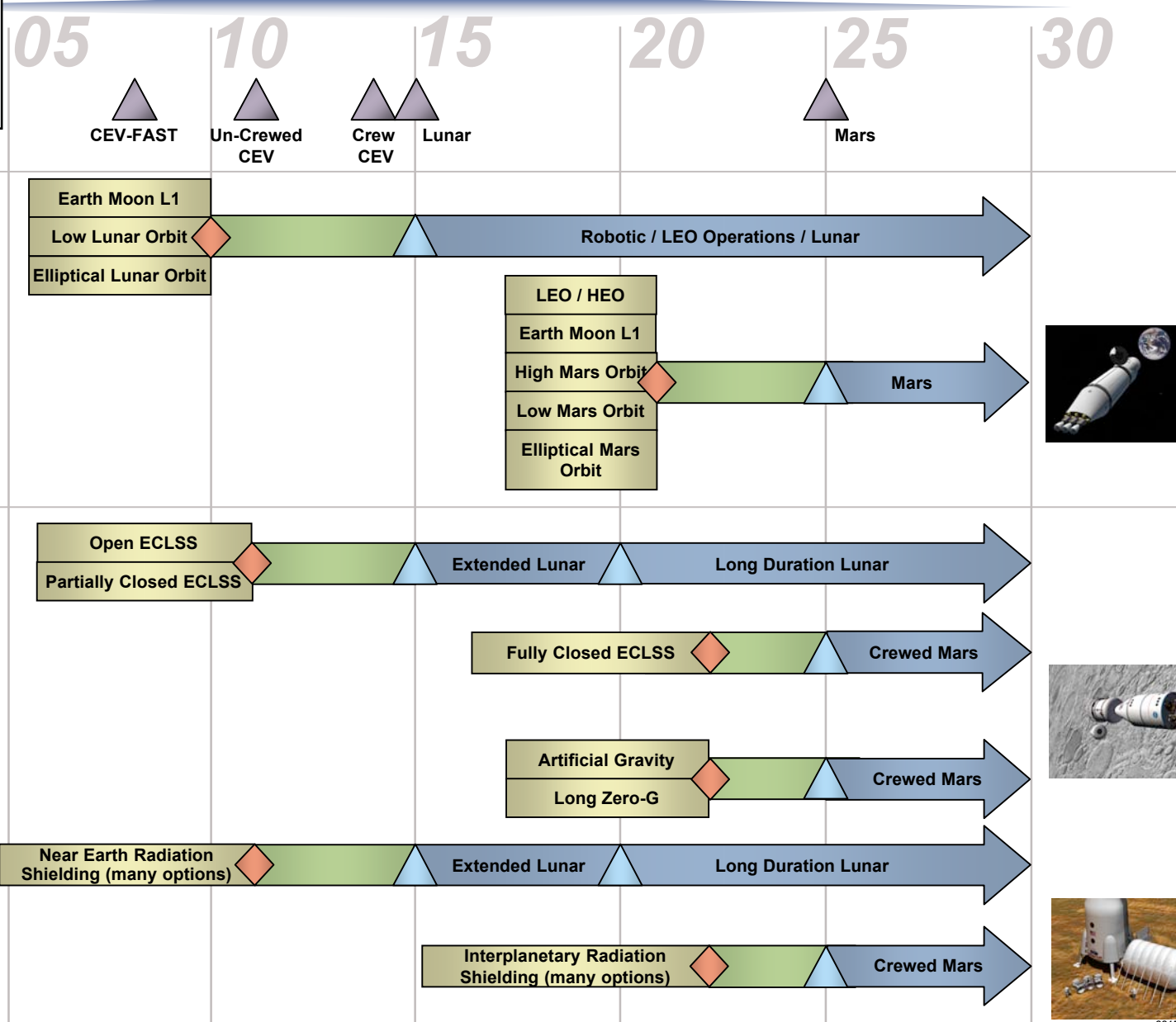
- ▲ - Program Milestone
- ◆ - Downselect Decision
- ▲ - IOC Milestone
- - Concept / Focused Technology
- - Development / Production
- - Operations / Support

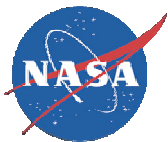
Trajectory

- Is gravity assist used?
- What is the nature of the parking orbit?

Crew Support

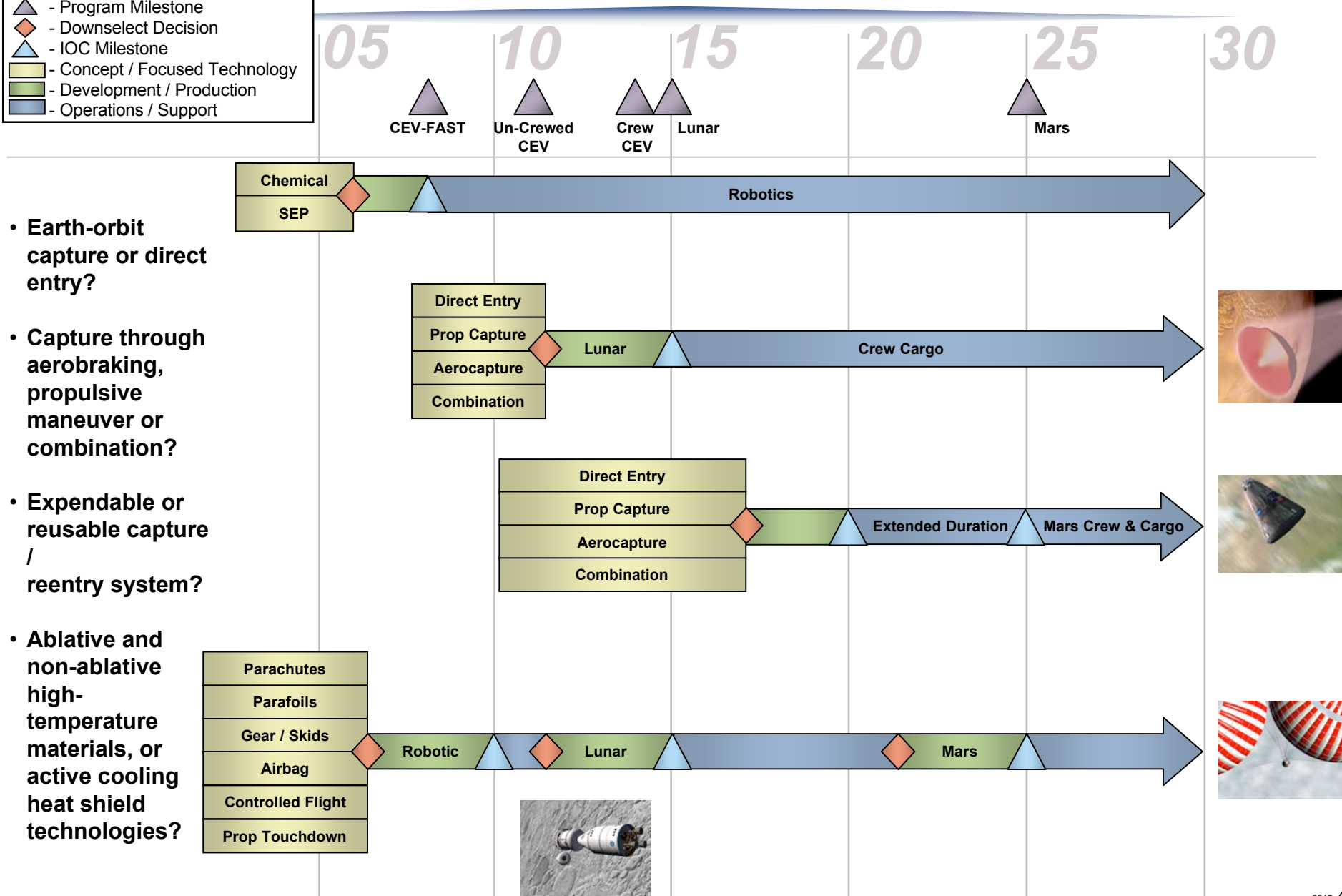
- When is the ECLSS system closed?
- Is artificial gravity required?
- How do we shield the crew from radiation?





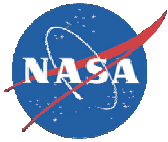
Earth Capture / Reentry Roadmap

- ▲ - Program Milestone
- ◆ - Downselect Decision
- ▲ - IOC Milestone
- - Concept / Focused Technology
- - Development / Production
- - Operations / Support



Supporting Information





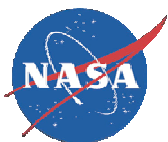
Space Transportation Needs Assessment

Spiral 1



Key Transportation Capabilities	Key Transportation Functions																		
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
Transportation Elements																			
ELV / EELV	X	O																	
EELV Derived	O	O																	
Shuttle Derived	O	O																	
Crew Exploration Vehicle		X			X														
Launch Escape System		X																	
Upper Stage / Transfer Stage				X	X		X			X			X			X			X
In-Space Propellant / Supply Depot																			
Planetary Capture / Entry							X						X						X
Planetary Landing							X						X						X
Surface Mobility							O			O			X			O			
Planetary Ascent										X						X			X
Reentry at Earth				X	X					X						X			X
Propulsion Systems																			
Chemical																			
Liquid																			
Cryogenics	X	X		O	O		O			O			O			O			O
Storables	X			X	X		O			O			O			O			O
Solid / Hybrid	X	O					O			O			O			O			O
Launch Assist	O	O																	
Nuclear Thermal																			
Electric																			
Low Power (<50kw)				O			O			O			O			O			X
Medium Power (50-500kw)							O			O			O			O			
High Power (>500kw)																			
Propellantless																			
Aeroassist (Capture / Entry)				O	X					O			O			O			O
Sails																			O
Tethers																			
Vehicle Systems																			
Lightweight Structures	O	O		O			O			X			X			X			X
Deployable Systems				O			O			X			X			X			X
Radiation Hardening / Shielding					O					O			O			O			O
MMOD Protection					O														
Efficient Thermal Systems							O			O			O			O			O
Avionics/Intelligent System Health Management	X	X		X	X		X			X			X			X			X
Power (generation, conversion, distribution)	X	X		X	X		X			X			X			X			X
Communications and Data Handling	X	X		X	X		X			X			X			X			X
Guidance, Navigation & Control	X	X		X	X		X			X			X			X			X
Reaction Control/Orbital Maneuvering	X	X		X	X		X			X			X			X			X
Cryo Fluid Management				O	O		O			O			O			O			
Systems Engineering and Integration (inc. M&S)	X	X		X	X		X			X			X			X			X
Human Systems																			
Life Support		X			X														
Radiation Protection																			
Biomedical Countermeasures																			
Crew Systems; In-space		X			X														
Crew Systems; Surface																			
Artificial Gravity																			
Operations																			
Automated																			
Rendezvous and Docking				X	O		O			O			O			O			O
Maneuvering				X	O		X			X			X			X			X
Decision Making				O			O			O			O			O			X
On-Orbit Assembly and/or Repair (EVA)					O														
Launch and Payload Processing / Range	X	X																	
Recovery				O	X					X						X			X
ISRU Propellants/Fluids																			
Propellant Transfer																			
Communications and Navigation Network	X	X		X	X		X			X			X			X			X
X - Probable Need O - Potential Need Difference Not Applicable																			

X - Probable Need O - Potential Need Difference Not Applicable



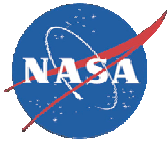
Space Transportation Needs

Difference Between Spiral 1 and 2



Key Transportation Capabilities	Key Transportation Functions																		
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
Transportation Elements																			
ELV / EELV	X	O	O																
EELV Derived	O	O	O																
Shuttle Derived	O	O	O																
Crew Exploration Vehicle		X			X			X			X								
Launch Escape System		X																	
Upper Stage / Transfer Stage				X	X			X	O		X		X			X			X
In-Space Propellant / Supply Depot																			
Planetary Capture / Entry								X	O				X						X
Planetary Landing								X	O				X						X
Surface Mobility								O					X			X			
Planetary Ascent											X					X	X		X
Reentry at Earth				X	X					X						X			X
Propulsion Systems																			
Chemical																			
Liquid																			
Cryogenics	X	X	X	O	O	O		X	O		X		O			O			O
Storables	X			X	X	X		O	O		X		O			O			O
Solid / Hybrid	X	O	O										O			O			O
Launch Assist	O	O	O																
Nuclear Thermal																			
Electric																			
Low Power (<50kw)				O		O							O			O			X
Medium Power (50-500kw)													O			O			X
High Power (>500kw)																			
Propellantless																			
Aeroassist (Capture / Entry)				O	X					X			O			O			X
Sails																			X
Tethers																			
Vehicle Systems																			
Lightweight Structures	O	O	O	O		O		O	O		O		O			X			X
Deployable Systems				O		O		X	O		X		O			X			X
Radiation Hardening / Shielding					O			X	O		X		O			O			O
MMOD Protection					O			X	O										
Efficient Thermal Systems								X	O		X		O			O			O
Avionics/Intelligent System Health Management	X	X	X	X	X	X		X	O		X					X			X
Power (generation, conversion, distribution)	X	X	X	X	X	X		X	O		X		X			X			X
Communications and Data Handling	X	X	X	X	X	X		X	O		X		X			X			X
Guidance, Navigation & Control	X	X	X	X	X	X		X	O		X		X			X			X
Reaction Control/Orbital Maneuvering	X	X	X	X	X	X		X	O		X		X			X			X
Cryo Fluid Management				O	O	X		X	O		X		O			O			
Systems Engineering and Integration (inc. M&S)	X	X	X	X	X	X		X	X		X		X			X			X
Human Systems																			
Life Support		X			X			X			X								
Radiation Protection								X			X								
Biomedical Countermeasures																			
Crew Systems; In-space		X			X			X			X								
Crew Systems; Surface								X											
Artificial Gravity																			
Operations																			
Automated																			
Rendezvous and Docking				X	X	X		O	O		X		O			O			O
Maneuvering				X	X	X		X	O		X		X			X			X
Decision Making				O		O		O	O		O		O			O			X
On-Orbit Assembly and/or Repair (EVA)					O	O		O	O		O								
Launch and Payload Processing / Range	X	X	X																
Recovery				O	X						X					X			X
ISRU Propellants/Fluids																			
Propellant Transfer						O		O	O										
Communications and Navigation Network	X	X	X	X	X	X		X	O		X		X			X			X
X - Probable Need O - Potential Need Difference Not Applicable																			

X - Probable Need O - Potential Need Difference Not Applicable



Space Transportation Needs

Spiral 2



Key Transportation Capabilities	Key Transportation Functions																		
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
Transportation Elements																			
ELV / EELV	X	O	O																
EELV Derived	O	O	O																
Shuttle Derived	O	O	O																
Crew Exploration Vehicle		X			X		X			X									
Launch Escape System		X																	
Upper Stage / Transfer Stage				X	X		X	O		X			X			X			X
In-Space Propellant / Supply Depot																			
Planetary Capture / Entry							X	O					X						X
Planetary Landing								O					X						X
Surface Mobility													X			X			
Planetary Ascent										X						X			X
Reentry at Earth				X	X					X						X			X
Propulsion Systems																			
Chemical																			
Liquid																			
Cryogenics	X	X	X	O	O	O	X	O		X			O			O			O
Storables	X			X	X	X	O	O		X			O			O			O
Solid / Hybrid	X	O	O										O			O			O
Launch Assist	O	O	O																
Nuclear Thermal																			
Electric																			
Low Power (<50kw)				O		O							O			O			X
Medium Power (50-500kw)													O			O			X
High Power (>500kw)																			
Propellantless																			
Aeroassist (Capture / Entry)				O	X					X			O			O			X
Sails																			X
Tethers																			
Vehicle Systems																			
Lightweight Structures	O	O	O	O		O		O		O			O			X			X
Deployable Systems				O		O				X			X			X			X
Radiation Hardening / Shielding					O					X			X			O			O
MMOD Protection					O					X									
Efficient Thermal Systems										X			X			O			O
Avionics/Intelligent System Health Management	X	X	X	X	X	X	X	O		X			X			X			X
Power (generation, conversion, distribution)	X	X	X	X	X	X	X	O		X			X			X			X
Communications and Data Handling	X	X	X	X	X	X	X	O		X			X			X			X
Guidance, Navigation & Control	X	X	X	X	X	X	X	O		X			X			X			X
Reaction Control/Orbital Maneuvering	X	X	X	X	X	X	X	O		X			X			X			X
Cryo Fluid Management				O	O	X				X			O			O			
Systems Engineering and Integration (inc. M&S)	X	X	X	X	X	X	X	X		X			X			X			X
Human Systems																			
Life Support		X			X			X			X								
Radiation Protection								X			X								
Biomedical Countermeasures																			
Crew Systems: In-space		X			X			X			X								
Crew Systems: Surface								X											
Artificial Gravity																			
Operations																			
Automated																			
Rendezvous and Docking				X	X	X		O	O		X		O			O			O
Maneuvering				X	X	X		X	O		X		X			X			X
Decision Making				O		O		O	O		O		O			O			X
On-Orbit Assembly and/or Repair (EVA)					O	O		O	O		O								
Launch and Payload Processing / Range	X	X	X																
Recovery				O	X						X					X			X
ISRU Propellants/Fluids																			
Propellant Transfer						O		O	O										
Communications and Navigation Network	X	X	X	X	X	X	X	X	O		X		X			X			X
X - Probable Need O - Potential Need Difference Not Applicable																			

X - Probable Need O - Potential Need Difference Not Applicable



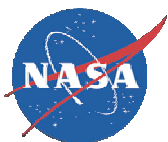
Space Transportation Needs

Difference Between Spiral 2 and 3



Key Transportation Capabilities	Key Transportation Functions																		
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
Transportation Elements																			
ELV / EELV	X	O	O																
EELV Derived	O	O	O																
Shuttle Derived	O	O	O																
Crew Exploration Vehicle		X			X		X			X									
Launch Escape System		X																	
Upper Stage / Transfer Stage				X	X		X	X		X	O	X				X			X
In-Space Propellant / Supply Depot						O					O								
Planetary Capture / Entry							X	X					X						X
Planetary Landing							X	X					X						X
Surface Mobility							X	X					X			X			
Planetary Ascent										X						X			X
Reentry at Earth				X	X					X						X			X
Propulsion Systems																			
Chemical																			
Liquid																			
Cryogenics	X	X	X	O	O	O		X	X		X		O			O			O
Storables	X			X	X	X		O	O		X		O			O			O
Solid / Hybrid	X	O	O										O			O			O
Launch Assist	O	O	O																
Nuclear Thermal									O										
Electric																			
Low Power (<50kw)				O		O							O	O		O			X
Medium Power (50-500kw)									O				O	O		O			X
High Power (>500kw)																			
Propellantless																			
Aeroassist (Capture / Entry)				O	X						X		O			O			X
Sails																			X
Tethers									O										
Vehicle Systems																			
Lightweight Structures	O	O	O	O		O		O	X		O	O	O			X			X
Deployable Systems				O		O		X	X		X	O	O			X			X
Radiation Hardening / Shielding					O			X	X		X	O	O			O			O
MMOD Protection					O			X	X			O							
Efficient Thermal Systems								X	X		X	O	O			O			O
Avionics/Intelligent System Health Management	X	X	X	X	X	X		X	X		X	O				X			X
Power (generation, conversion, distribution)	X	X	X	X	X	X		X	X		X	O	X			X			X
Communications and Data Handling	X	X	X	X	X	X		X	X		X	O	X			X			X
Guidance, Navigation & Control	X	X	X	X	X	X		X	X		X	O	X			X			X
Reaction Control/Orbital Maneuvering	X	X	X	X	X	X		X	X		X	O	X			X			X
Cryo Fluid Management				O	O	X		X	X		X	O	O			O			
Systems Engineering and Integration (inc. M&S)	X	X	X	X	X	X		X	X		X	O	X			X			X
Human Systems																			
Life Support		X			X			X			X								
Radiation Protection								X			X								
Biomedical Countermeasures																			
Crew Systems; In-space		X			X			X			X								
Crew Systems; Surface								X											
Artificial Gravity																			
Operations																			
Automated																			
Rendezvous and Docking				X	X	X		O	O		X	O	O			O			O
Maneuvering				X	X	X		X	X		X	O	X			X			X
Decision Making				O		O		O	X		O	O	O			O			X
On-Orbit Assembly and/or Repair (EVA)					O	O		O	X										
Launch and Payload Processing / Range	X	X	X																
Recovery				O	X						X					X			X
ISRU Propellants/Fluids								O				O							
Propellant Transfer				O	O	O		O	X				O						
Communications and Navigation Network	X	X	X	X	X	X		X	X		X		X			X			X

X - Probable Need O - Potential Need Difference Not Applicable



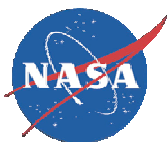
Space Transportation Needs

Spiral 3



Key Transportation Capabilities	Key Transportation Functions																		
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
Transportation Elements																			
ELV / EELV	X	O	O																
EELV Derived	O	O	O																
Shuttle Derived	O	O	O																
Crew Exploration Vehicle		X			X		X			X									
Launch Escape System		X																	
Upper Stage / Transfer Stage				X	X		X	X		X	O	X				X			X
In-Space Propellant / Supply Depot						O			O										
Planetary Capture / Entry							X	X											X
Planetary Landing							X	X				X							X
Surface Mobility							X	X				X				X			
Planetary Ascent										X						X			X
Reentry at Earth				X	X					X						X			X
Propulsion Systems																			
Chemical																			
Liquid																			
Cryogenics	X	X	X	O	O	O	X	X		X			O			O			O
Storables	X			X	X	X	O	O		X			O			O			O
Solid / Hybrid	X	O	O										O			O			O
Launch Assist	O	O	O						O										
Nuclear Thermal																			
Electric																			
Low Power (<50kw)				O		O			O			O	O			O			X
Medium Power (50-500kw)									O			O	O			O			X
High Power (>500kw)																			
Propellantless																			
Aeroassist (Capture / Entry)				O	X					X			O			O			X
Sails																			X
Tethers									O										
Vehicle Systems																			
Lightweight Structures	O	O	O	O		O		O	X		O	O	O			X			X
Deployable Systems				O		O		X	X		X	O	O			X			X
Radiation Hardening / Shielding					O			X	X		X	O	O			O			O
MMOD Protection					O			X	X			O							
Efficient Thermal Systems								X	X		X	O	O			O			O
Avionics/Intelligent System Health Management	X	X	X	X	X	X	X	X	X		X	O				X			X
Power (generation, conversion, distribution)	X	X	X	X	X	X	X	X	X		X	O	X			X			X
Communications and Data Handling	X	X	X	X	X	X	X	X	X		X	O	X			X			X
Guidance, Navigation & Control	X	X	X	X	X	X	X	X	X		X	O	X			X			X
Reaction Control/Orbital Maneuvering	X	X	X	X	X	X	X	X	X		X	O	X			X			X
Cryo Fluid Management				O	O		X	X	X		X	O	O			O			
Systems Engineering and Integration (inc. M&S)	X	X	X	X	X	X	X	X	X		X	O	X			X			X
Human Systems																			
Life Support		X			X			X			X								
Radiation Protection								X			X								
Biomedical Countermeasures																			
Crew Systems: In-space		X			X			X			X								
Crew Systems: Surface								X											
Artificial Gravity																			
Operations																			
Automated																			
Rendezvous and Docking				X	X	X		O	O		X	O	O			O			O
Maneuvering				X	X	X		X	X		X	O	X			X			X
Decision Making				O		O		O	X		O	O	O			O			X
On-Orbit Assembly and/or Repair (EVA)					O	O		O	X		X								
Launch and Payload Processing / Range	X	X	X																
Recovery				O	X						X					X			X
ISRU Propellants/Fluids								O			O								
Propellant Transfer				O	O	O		O	X			O							
Communications and Navigation Network	X	X	X	X	X	X	X	X	X		X		X			X			X
X - Probable Need O - Potential Need Difference Not Applicable																			

X - Probable Need O - Potential Need Difference Not Applicable



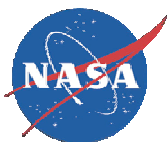
Space Transportation Needs

Difference Between Spiral 3 and 4/5



Key Transportation Capabilities	Key Transportation Functions																		
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
Transportation Elements																			
ELV / EELV	X	O	O																
EELV Derived	O	O	O																
Shuttle Derived	O	O	O																
Crew Exploration Vehicle		X			X			X			X			X			X		
Launch Escape System		X																	
Upper Stage / Transfer Stage				X	X			X	X		X	O	X	X	O	X	X	O	X
In-Space Propellant / Supply Depot						O			O		O			O	O		O	O	
Planetary Capture / Entry								X	X				X	X	O				X
Planetary Landing								X	X				X	X	O				X
Surface Mobility								X	X				X	X	O				
Planetary Ascent											X					X	X		X
Reentry at Earth				X	X					X						X	X		X
Propulsion Systems																			
Chemical																			
Liquid																			
Cryogenics	X	X	X	O	O	O		X	X		X		O	X	O	O	X		O
Storables	X			X	X	X		O	O		X		O	O	O	O	X		O
Solid / Hybrid	X	O	O										O			O			O
Launch Assist	O	O	O																
Nuclear Thermal									O					O	O		O	O	O
Electric																			
Low Power (<50kw)				O		O					O	O	O			O			X
Medium Power (50-500kw)									O			O	O		O			O	X
High Power (>500kw)													O	O		O	O		
Propellantless																			
Aeroassist (Capture / Entry)				O	X					X		O	O	X	O	X			X
Sails																			X
Tethers									O						O				
Vehicle Systems																			
Lightweight Structures	O	O	O	O		O		O	X		O	O	O	X	X	X	O	O	X
Deployable Systems				O		O		X	X		X	O	O	X	O	X	X	O	X
Radiation Hardening / Shielding					O			X	X		X	O	O	X	O	O	X	O	O
MMOD Protection					O			X	X			O		X	O			O	
Efficient Thermal Systems								X	X		X	O	O	X	O	O	X	O	O
Avionics/Intelligent System Health Management	X	X	X	X	X	X		X	X		X	O		X	O	X	X	O	X
Power (generation, conversion, distribution)	X	X	X	X	X	X		X	X		X	O	X	X	O	X	X	O	X
Communications and Data Handling	X	X	X	X	X	X		X	X		X	O	X	X	O	X	X	O	X
Guidance, Navigation & Control	X	X	X	X	X	X		X	X		X	O	X	X	O	X	X	O	X
Reaction Control/Orbital Maneuvering	X	X	X	X	X	X		X	X		X	O	X	X	O	X	X	O	X
Cryo Fluid Management				O	O	X		X	X		X	O	O	X	O	O	X	O	
Systems Engineering and Integration (inc. M&S)	X	X	X	X	X	X		X	X		X	O	X	X	X	X	X	O	X
Human Systems																			
Life Support		X			X			X			X			X			X		
Radiation Protection								X			X			X			X		
Biomedical Countermeasures														X					
Crew Systems; In-space		X			X			X			X			X			X		
Crew Systems; Surface								X						X					
Artificial Gravity														O					
Operations																			
Automated																			
Rendezvous and Docking				X	X	X		O	O		X	O	O	O	O	O	X	O	O
Maneuvering				X	X	X		X	X		X	O	X	X	O	X	X	O	X
Decision Making				O		O		O	X		O	O	O	O	O	O	O	O	X
On-Orbit Assembly and/or Repair (EVA)					O	O		O	X		X			X	O		X		
Launch and Payload Processing / Range	X	X	X																
Recovery				O	X						X					X	X		X
ISRU Propellants/Fluids								O						X			O		
Propellant Transfer				O	O	O		O	X			O		O	O		O	O	
Communications and Navigation Network	X	X	X	X	X	X		X	X		X		X	X	O	X	X		X
X - Probable Need O - Potential Need Difference Not Applicable																			

X - Probable Need O - Potential Need Difference Not Applicable



Space Transportation Needs

Spiral 4/5



Key Transportation Capabilities	Key Transportation Functions																		
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
Transportation Elements																			
ELV / EELV	X	O	O																
EELV Derived	O	O	O																
Shuttle Derived	O	O	O																
Crew Exploration Vehicle		X			X			X			X			X			X		
Launch Escape System		X																	
Upper Stage / Transfer Stage				X	X			X	X		X	O	X	X	O	X	X	O	X
In-Space Propellant / Supply Depot						O			O		O			O	O		O	O	
Planetary Capture / Entry								X	X				X	X	O				X
Planetary Landing								X	X				X	X	O				X
Surface Mobility								X	X				X	X	O				
Planetary Ascent											X					X	X		X
Reentry at Earth				X	X						X					X	X		X
Propulsion Systems																			
Chemical																			
Liquid																			
Cryogenics	X	X	X	O	O	O		X	X		X		O	X	O	O	X		O
Storables	X			X	X	X		O	O		X		O	O	O	O	X		O
Solid / Hybrid	X	O	O										O			O			O
Launch Assist	O	O	O																
Nuclear Thermal									O					O	O		O	O	O
Electric																			
Low Power (<50kw)				O		O			O			O	O			O			X
Medium Power (50-500kw)									O			O	O		O			O	X
High Power (>500kw)														O	O		O	O	
Propellantless																			
Aeroassist (Capture / Entry)				O	X					X			O	O	X	O	X		X
Sails																O			X
Tethers									O							O			
Vehicle Systems																			
Lightweight Structures	O	O	O	O		O		O	X		O	O	O	X	X	X	O	O	X
Deployable Systems				O		O			X	X		X	O	O	X	O	X	O	X
Radiation Hardening / Shielding					O				X	X		X	O	O	O	O	X	O	O
MMOD Protection					O				X	X			O		X	O		O	O
Efficient Thermal Systems									X	X		X	O	O	X	O	X	O	O
Avionics/Intelligent System Health Management	X	X	X	X	X	X			X	O		X	O		X	O	X	O	X
Power (generation, conversion, distribution)	X	X	X	X	X	X			X	X		X	O	X	X	O	X	O	X
Communications and Data Handling	X	X	X	X	X	X			X	X		X	O	X	X	O	X	O	X
Guidance, Navigation & Control	X	X	X	X	X	X			X	X		X	O	X	X	O	X	X	X
Reaction Control/Orbital Maneuvering	X	X	X	X	X	X			X	X		X	O	X	X	O	X	O	X
Cryo Fluid Management				O	O				X	X		X	O	O	X	O	O	X	
Systems Engineering and Integration (inc. M&S)	X	X	X	X	X	X			X	X		X	O	X	X	X	X	O	X
Human Systems																			
Life Support		X			X				X			X			X		X		
Radiation Protection									X			X					X		
Biomedical Countermeasures																			
Crew Systems; In-space		X			X				X			X					X		
Crew Systems; Surface									X										
Artificial Gravity														O					
Operations																			
Automated																			
Rendezvous and Docking				X	X	X			O	O		X	O	O	O	O	O	X	O
Maneuvering				X	X	X			X	X		X	O	X	X	O	X	X	O
Decision Making				O		O			O	X		O	O	O	O	O	O	O	X
On-Orbit Assembly and/or Repair (EVA)					O	O			O	X		X					X		
Launch and Payload Processing / Range	X	X	X																
Recovery				O	X							X					X	X	
ISRU Propellants/Fluids									O						X			O	
Propellant Transfer				O	O	O			O	X			O		O			O	
Communications and Navigation Network	X	X	X	X	X	X			X	X		X		X	X	O	X	X	
X - Probable Need O - Potential Need Difference Not Applicable																			

X - Probable Need O - Potential Need Difference Not Applicable



Analysis of Capability Need Across Spirals



	Key Transportation Functions																		
Key Transportation Capabilities	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
Transportation Elements																			
ELV / EELV	4/0/4	0/4/4	0/3/3																
EELV Derived	0/4/4	0/4/4	0/3/3																
Shuttle Derived	0/4/4	0/4/4	0/3/3																
Crew Exploration Vehicle		4/0/4			4/0/4			3/0/3			3/0/3			1/0/1			1/0/1		
Launch Escape System		4/0/4																	
Upper Stage / Transfer Stage				4/0/4	4/0/4		1/0/1	3/0/3	2/1/3	1/0/1	3/0/3	0/2/2	4/0/4	1/0/1	0/1/1	4/0/4	1/0/1	0/1/1	4/0/4
In-Space Propellant / Supply Depot						0/2/2			0/2/2			0/2/2		0/1/1	0/1/1		0/1/1	0/1/1	
Planetary Capture / Entry							1/0/1	3/0/3	2/1/3				4/0/4	1/0/1	0/1/1				4/0/4
Planetary Landing							1/0/1	3/0/3	2/1/3				4/0/4	1/0/1	0/1/1				4/0/4
Surface Mobility							0/1/1	2/1/3	2/0/2		0/1/1		4/0/4	1/0/1	0/1/1	3/1/4			
Planetary Ascent										1/0/1	3/0/3					4/0/4	1/0/1		4/0/4
Reentry at Earth				4/0/4	4/0/4					1/0/1	3/0/3					4/0/4	1/0/1		4/0/4
Propulsion Systems																			
Chemical																			
Liquid																			
Cryogenics	4/0/4	4/0/4	3/0/3	0/4/4	0/4/4	0/3/3	0/1/1	3/0/3	2/1/3	0/1/1	3/0/3		0/4/4	1/0/1	0/1/1	0/4/4	1/0/1		0/4/4
Storables	4/0/4			4/0/4	4/0/4	3/0/3	0/1/1	0/3/3	0/3/3	0/1/1	3/0/3		0/4/4	0/1/1	0/1/1	0/4/4	1/0/1		0/4/4
Solid / Hybrid	4/0/4	0/4/4	0/3/3				0/1/1			0/1/1			0/4/4			0/4/4			0/4/4
Launch Assist	0/4/4	0/4/4	0/3/3																
Nuclear Thermal									0/2/2					0/1/1	0/1/1		0/1/1	0/1/1	0/1/1
Electric																			
Low Power (<50kw)				0/4/4		0/3/3	0/1/1		0/2/2	0/1/1		0/2/2	0/4/4			0/4/4			4/0/4
Medium Power (50-500kw)							0/1/1		0/2/2	0/1/1		0/2/2	0/4/4		0/1/1	0/4/4		0/1/1	3/0/3
High Power (>500kw)														0/1/1	0/1/1		0/1/1	0/1/1	
Propellantless																			
Aeroassist (Capture / Entry)				0/4/4	4/0/4					0/1/1	3/0/3		0/4/4	0/1/1	1/0/1	0/4/4	1/0/1		3/1/4
Sails															0/1/1				3/1/4
Tethers									0/2/2						0/1/1				
Vehicle Systems																			
Lightweight Structures	0/4/4	0/4/4	0/3/3	0/4/4		0/3/3	0/1/1	0/3/3	2/1/3	1/0/1	0/3/3	0/2/2	1/3/4	1/0/1	1/0/1	4/0/4	0/1/1	0/1/1	4/0/4
Deployable Systems				0/4/4		0/3/3	0/1/1	3/0/3	2/1/3	1/0/1	3/0/3	0/2/2	1/3/4	1/0/1	0/1/1	4/0/4	1/0/1	0/1/1	4/0/4
Radiation Hardening / Shielding					0/4/4		0/1/1	3/0/3	2/1/3	0/1/1	3/0/3	0/2/2	0/4/4	1/0/1	0/1/1	0/4/4	1/0/1	0/1/1	0/4/4
MMOD Protection					0/4/4			3/0/3	2/1/3			0/2/2		1/0/1	0/1/1			0/1/1	
Efficient Thermal Systems							0/1/1	3/0/3	2/1/3	0/1/1	3/0/3	0/2/2	0/4/4	1/0/1	0/1/1	0/4/4	1/0/1	0/1/1	0/4/4
Avionics/Intelligent System Health Management	4/0/4	4/0/4	3/0/3	4/0/4	4/0/4	3/0/3	1/0/1	3/0/3	2/1/3	1/0/1	3/0/3	0/2/2	1/0/1	1/0/1	0/1/1	4/0/4	1/0/1	0/1/1	4/0/4
Power (generation, conversion, distribution)	4/0/4	4/0/4	3/0/3	4/0/4	4/0/4	3/0/3	1/0/1	3/0/3	2/1/3	1/0/1	3/0/3	0/2/2	4/0/4	1/0/1	0/1/1	4/0/4	1/0/1	0/1/1	4/0/4
Communications and Data Handling	4/0/4	4/0/4	3/0/3	4/0/4	4/0/4	3/0/3	1/0/1	3/0/3	2/1/3	1/0/1	3/0/3	0/2/2	4/0/4	1/0/1	0/1/1	4/0/4	1/0/1	0/1/1	4/0/4
Guidance, Navigation & Control	4/0/4	4/0/4	3/0/3	4/0/4	4/0/4	3/0/3	1/0/1	3/0/3	2/1/3	1/0/1	3/0/3	0/2/2	4/0/4	1/0/1	0/1/1	4/0/4	1/0/1	0/1/1	4/0/4
Reaction Control/Orbital Maneuvering	4/0/4	4/0/4	3/0/3	4/0/4	4/0/4	3/0/3	1/0/1	3/0/3	2/1/3	1/0/1	3/0/3	0/2/2	4/0/4	1/0/1	0/1/1	4/0/4	1/0/1	0/1/1	4/0/4
Cryo Fluid Management				0/4/4	0/4/4	3/0/3	0/1/1	3/0/3	2/1/3	0/1/1	3/0/3	0/2/2	0/4/4	1/0/1	0/1/1	0/4/4	1/0/1	0/1/1	
Systems Engineering and Integration (inc. M&S)	4/0/4	4/0/4	3/0/3	4/0/4	4/0/4	3/0/3	1/0/1	3/0/3	3/0/3	1/0/1	3/0/3	0/2/2	4/0/4	1/0/1	1/0/1	4/0/4	1/0/1	0/1/1	4/0/4
Human Systems																			
Life Support		4/0/4			4/0/4			3/0/3			3/0/3			1/0/1			1/0/1		
Radiation Protection								3/0/3			3/0/3			1/0/1			1/0/1		
Biomedical Countermeasures														1/0/1					
Crew Systems; In-space		4/0/4			4/0/4			3/0/3			3/0/3			1/0/1			1/0/1		
Crew Systems; Surface								3/0/3						1/0/1					
Artificial Gravity														0/1/1					
Operations																			
Automated																			
Rendezvous and Docking				4/0/4	3/1/4	3/0/3	0/1/1	0/3/3	0/3/3	0/1/1	3/0/3	0/2/2	0/4/4	0/1/1	0/1/1	0/4/4	1/0/1	0/1/1	0/4/4
Maneuvering				4/0/4	3/1/4	3/0/3	1/0/1	3/0/3	2/1/3	1/0/1	3/0/3	0/2/2	4/0/4	1/0/1	0/1/1	4/0/4	1/0/1	0/1/1	4/0/4
Decision Making				0/4/4		0/3/3	0/1/1	0/3/3	2/1/3	0/1/1	0/3/3	0/2/2	0/4/4	0/1/1	0/1/1	0/4/4	0/1/1	0/1/1	4/0/4
On-Orbit Assembly and/or Repair (EVA)					0/4/4	0/3/3		0/3/3	2/1/3		2/1/3			1/0/1	0/1/1		1/0/1		
Launch and Payload Processing / Range	4/0/4	4/0/4	3/0/3																
Recovery				0/4/4	4/0/4					1/0/1	3/0/3					4/0/4	1/0/1		4/0/4
ISRU Propellants/Fluids								0/2/2			0/1/1			1/0/1			0/1/1		
Propellant Transfer				0/2/2	0/2/2	0/3/3		0/3/3	2/1/3			0/2/2		0/1/1	0/1/1		0/1/1	0/1/1	
Communications and Navigation Network	4/0/4	4/0/4	3/0/3	4/0/4	4/0/4	3/0/3	1/0/1	3/0/3	2/1/3	1/0/1	3/0/3		4/0/4	1/0/1	0/1/1	4/0/4	1/0/1		4/0/4

Legend:
Number of Probable / Potential / Total